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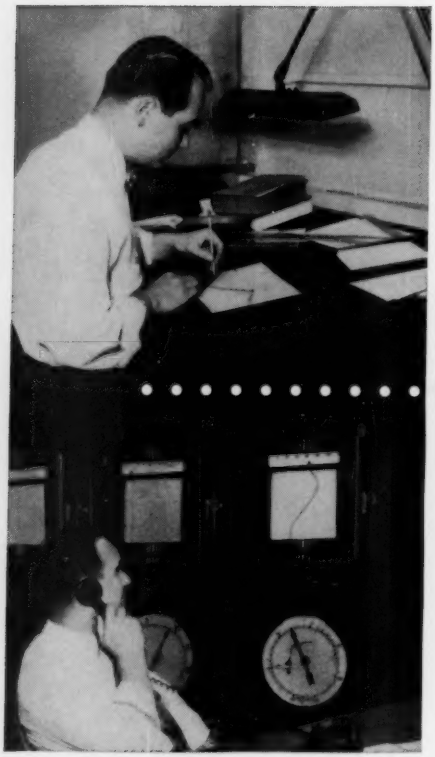

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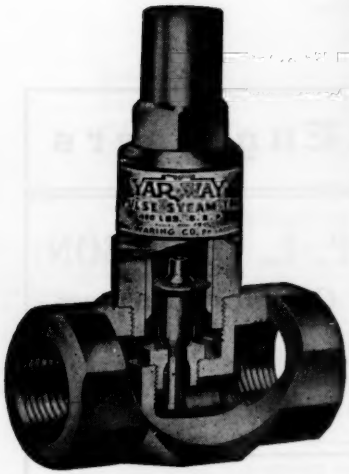

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The new amplifier's tremendous bandwidth greatly simplifies the practical problem of operating and maintaining microwave communications. For example, in the proposed transcontinental system, as many as 16 different one-way radio channels will be used to transmit a capacity load of more than 11,000 conversations or 12 television programs and 2500 conversations. Formerly it would have been necessary to tune several amplifier tubes to match each channel. In contrast, a single traveling-wave tube can supply all the amplification needed for a channel. Tubes can be interchanged with only very minor adjustments.

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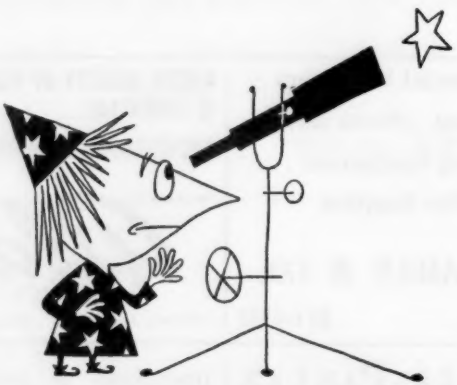

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Vol. 264 NOVEMBER, 1957 No. 5

THE DESIGN OF A CREVASSE DETECTOR FOR POLAR EXPLORATION

BY

JOHN C. COOK [1]

ABSTRACT

A recently discovered electrical method for locating dangerous covered crevasses has been successfully reduced to practice. Some tentative design principles for a practical vehicular crevasse detector have been formulated. These have been embodied in fifteen experimental units now available to U. S. government agencies in the polar regions. Each such unit includes a flexible array of 20 ft-long. timbers controlling a group of 43-in. dish-shaped electrode sleds which is pushed ahead of a "weasel" vehicle, additional electrodes dragged behind, and a suitable electrical system including a signal-indicating ink recorder and an adjustable alarm system responding to abnormal signal levels. One unit of this equipment has given valuable assistance in early Antarctic over-ice operations for the IGY. However, further improvements are desirable and many uncertainties remain unresolved by field experience at this time.

A. INTRODUCTION

Increasing military and other over-ice vehicular traffic in the polar regions during the past decade has demanded that improved means of locating covered crevasses be developed. Fortunately, an effective electrical method (1)[2] of locating crevasses was invented in 1955 at Southwest Research Institute under the sponsorship of the U. S. Army Engineer Research and Development Laboratories (ERDL). The theory of the method and some preliminary results obtained with it have been summarized elsewhere (1). This paper explains and describes the design of the practical crevasse detecting equipment developed subsequently, with emphasis upon the latest, improved models.

[1] Manager, Geophysical Engineering Section, Southwest Research Institute, San Antonio, Texas.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

1. Technical Background

The working principle of the present crevasse detectors may be interpreted in several ways. A particularly simple view is as follows: the apparent dielectric constant of a chosen large volume of ice or firn is measured continuously by apparatus moving over its surface. A crevasse or other large void concealed in the ice or firn locally reduces the effective dielectric constant from its usual value of 30 to 75 cgs. (at low audio frequencies) to a value near unity. The apparatus locates this anomaly.

Figure 1 summarizes the essentials of the required apparatus. Four

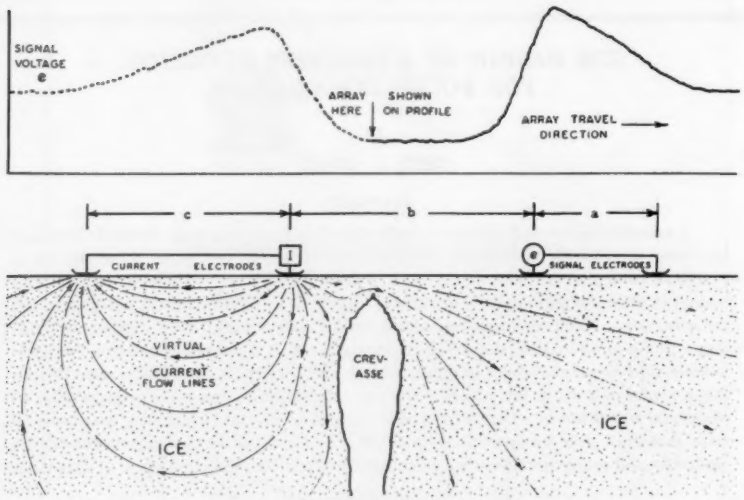


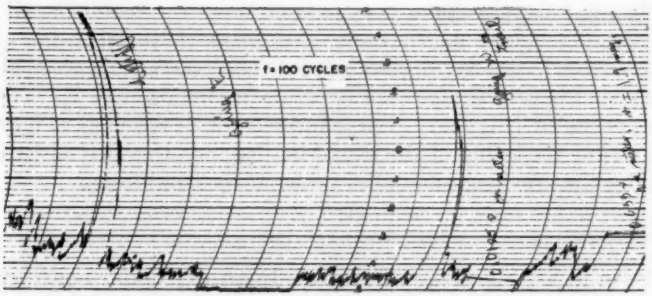
FIG. 1. Typical crevasse cross section, electrode system and diagnostic signal profile for $b > 35$ ft.

electrodes of large area are arranged in a rigid pattern capable of moving as a whole over the ice surface. A source of alternating current I is connected between the two current electrodes. These establish a three-dimensional pattern of virtual or "displacement" current flowing in the ice, which is a good insulator. A potential-difference-measuring device, such as an a-c. voltmeter, is connected between the other two electrodes, called the potential or signal electrodes. These sense, in effect, the current density in a surrounding volume of the ice. A preliminary working equation for an in-line system of electrodes on homogeneous ice is:

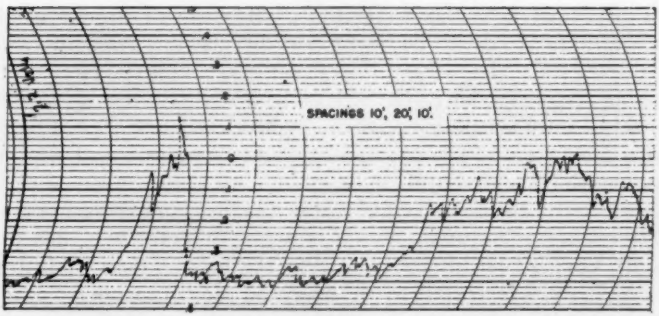
$$e = \frac{I}{4\pi^2 Bfk}\left[\frac{1}{b} - \frac{1}{b+c} - \frac{1}{a+b} + \frac{1}{a+b+c}\right]$$

where e is signal in volts rms., I is applied current in amperes rms., f is frequency in cps., k is the effective cgs. dielectric constant of the ice, $B = 1.11 \times 10^{-12}$ farads/esu., and a, b, and c are the electrode spacings shown in Fig. 1 in centimeters.

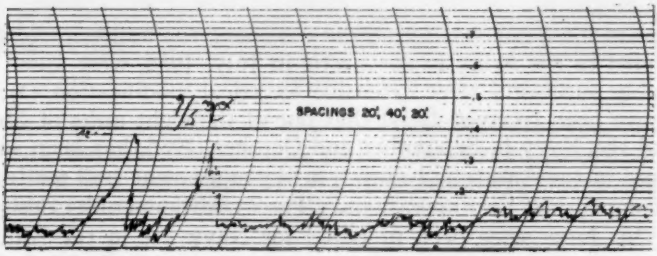
Any marked distortion of the current pattern by an obstruction, such as might result from introduction of a crevasse near any of the



(*a*) Typical "good" anomalies. In-line system. $a = b = c = 25$ ft.



(*b*) Anomaly and "bad background variation." In-line system. $f = 60$ cycles.



(*c*) Typical depressed center large spacing anomaly. Same conditions as (*b*), showing smoothed background. In-line system. $f = 60$ cycles.

FIG. 2. Examples of crevasse anomaly test recordings.

electrodes, will cause a change in the voltage reading *e*. It has been found that most crevasses produce voltmeter readings from two to twenty times as large as the "normal" signal and its fluctuations over an uncrevassed glacier. Figure 2*a* shows an ink-recording of a typical crevasse indication, made with early experimental equipment on Arctic land ice. Crevasses in floating Antarctic shelf ice, in contrast, sometimes are indicated by a drop in reading to one-half or even one-twelfth of the "normal" signal (2).

Background signal fluctuations, presumed to result from narrow cracks and from local variations of snow density and structure, also occur and are sometimes so severe that crevasse anomalies may be overshadowed or concealed (Fig. 2*b*). Large interelectrode spacings (Figs. 1 and 2*c*) and visible recording of the signal-*vs*.-distance-traveled assist in distinguishing the crevasse anomalies under these conditions.

2. Development

Early in 1956, Southwest Research Institute, under contract with ERDL, undertook the design and construction of several units of an Engineer Test Model crevasse detector. These units were also to be used for practical field reconnaissance. Because of urgent need, the required equipment had to be developed directly from results obtained with the first crude "breadboard" test setups. This development was, furthermore, performed without access to a realistic test situation and in a period of only six months (through Models 1 and 2). The equipment also incorporated several radical improvements, and was, therefore, necessarily experimental.

Consequently, the design chosen was a rather complex one providing several alternative features. Each crevasse detector was also made a *double* unit, having two different electrical systems and electrode arrangements which were intended to be operated simultaneously, as double insurance against missing any crevasses. Furthermore, the components of either system could be used as spares for the other, if required in emergencies.

Despite the handicaps facing the designers, the four units of Model 1 delivered to the Army in the Arctic in July, 1956, were found to be reasonably successful after extensive electrical modification (3). Reports have been received (2, 4) that one of the eight units of Model 2 supplied the Navy in September and October, 1956, has been successfully used in the Antarctic to test a heavy-equipment trail for International Geophysical Year operations. Three additional units, designated Model 2A, have since been prepared for Navy use in the Antarctic. Valuable field observations and further equipment improvements will undoubtedly result from the use of these units by Navy and IGY personnel and by the Army and research contractors.

B. MECHANICAL DESIGN

1. Electrode Arrangements

The electrodes may be arranged in a wide variety of patterns. A "wide" arrangement, consisting of a line of four electrodes moving abreast, was considered probably to be the best for the following reasons:

a. It tests a wide path surrounding the vehicle.

b. Its sensitivity is concentrated in a small area far ahead of the vehicle, giving the earliest warning.

c. Its crevasse anomalies tend to be of the simple "square topped" type which stand out well on a recording and also should indicate the crevasse width directly (similar to Fig. 2*a*).

However, this system cannot easily provide the large electrode spacings which appear to be necessary to detect thickly-bridged crevasses which may be dangerous to heavy tractors. Large spacings are also necessary in order to discriminate against certain kinds of background fluctuations. Therefore, a "long" arrangement (a line of electrodes moving parallel to its length) with larger spacings should be used as a check. Figure 3 shows one possible physical arrangement of the result-

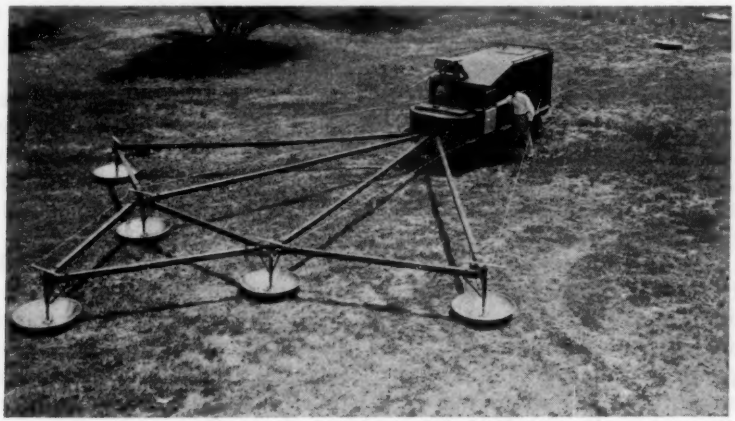


FIG. 3. Double crevasse detector (Model 1) at Laboratory.

ing double system. The arc of four electrodes preceding the "weasel" vehicle constitutes a wide system. The long system consists of the single leading sled and the weasel acting as signal electrodes, and two towed sleds acting as power electrodes.

2. Electrode Spacings

The spacings and arrangement of the electrodes determine the "effective ice-sampling depth" of the system. In general, the smallest

spacing between any pair of the four electrodes should exceed the thickness of the thickest crevasse bridge likely to be encountered. Spacing "b" is probably the most important and should be largest.

a. The wide system is limited by maneuvering and structural problems to spacings *a*, *b*, *c* or 10, 10, and 10 ft. This was judged adequate for early warning and for accurate location of most crevasses dangerous to weasels.

b. The long system requires spacings of at least 10, 40, and 10 ft. according to experiment. With the boom arrangement shown in Fig. 3, ample spacings of 28, 40, and 40 ft. can be provided. The use of these wider spacings should make it possible to distinguish between crevasses and other effects, and to detect those which have thick bridges.

3. Electrode Size and Shape

In order to negotiate successfully the irregular ice surfaces often found in the Polar regions, a minimum length of 3 ft. and a height of 6 in. are desirable. Furthermore, the forward four sleds must support the weight of the hardware, the spars and half that of the thrust booms, a total weight of 100 to 125 lb. per sled, without sinking in excessively on loose, granular snow. Sleds having areas of from 3 to 12 sq. ft. should be used to secure both good flotation and effective electrical contact with the snow.

The close spacing of the sleds in the wide array should be maintained unchanged during turns. Therefore, long, thin electrodes which must swivel in order to negotiate turns are not usable since the ends would approach each other in swiveling, thereby altering the spacings and producing a false signal. A circular sled pivoted at its center (if at all) is the only shape free from this effect.

Therefore, a circular "dish" sled which has an 18 in.-diameter flat bottom, joined by a smooth curve rising 9 in. to an over-all diameter of 43 in., was selected (Figs. 3 and 4). A $\frac{3}{4}$-in. rolled bead around the rim provides stiffness and durability. These sleds were custom-spun by the Superior Spinning & Stamping Co., of Toledo, from a $\frac{1}{8}$-in. thick, heat-treat-workable aluminum alloy (52-S or equivalent). They weigh only 25 lb. each and nest together for shipment.

Field use of these sleds has shown them to be mechanically satisfactory. Nevertheless, a larger size would have been desirable since their electrical impedances were found to be of the order of 2 megohms each under field conditions (3). A dish 12 in. high and $\frac{3}{16}$ in. thick, with a flat bottom 36 in. in diameter and an over-all diameter of about 60 in., would probably have a $\frac{1}{2}$-megohm impedance and would give much improved electrical performance.

In particular, sleds of lower impedance should greatly reduce the background signal fluctuations associated with sastrugi and near-surface variations of snow density, which seriously obscured the crevasse anom-

alies recorded by Smith and Anderson (4). Impedance (and signal) variations arising at the signal sleds from this cause would become unimportant if the average electrode impedance were comparable to or smaller than the impedance of the signal-input circuit (nominally 200,000 ohms).

The towed sleds for the long system should have sharp, sturdy guiding keels about one-half in. tall, and "brakes" to prevent them from coasting out of control when descending hard-surfaced slopes. Large rectangular rear sleds with "non-skid" bottom surfaces of coarse-perforated steel are suggested for future units.

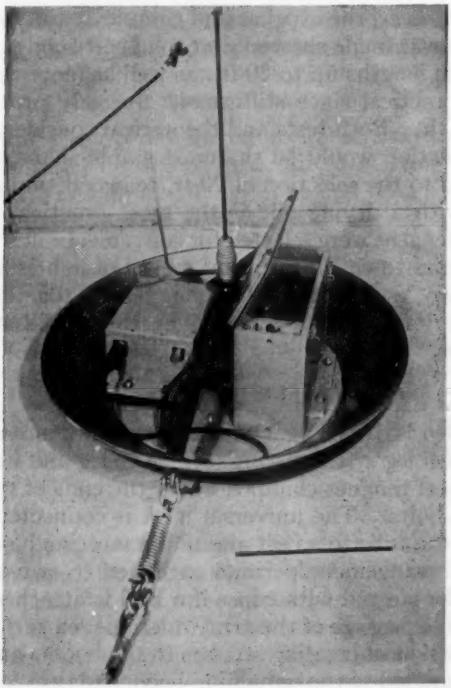


FIG. 4. Sled power unit (Model 1A).

4. Forward Boom Structure

The problem of making a light horizontal boom, suspended at its ends by the weasel and by the electrode sleds, required much study. A boom of plastic pipe used in early Antarctic tests had been unsatisfactory (2). The mechanical stability of such a boom in compression depends largely on its deflection (sag) caused by gravity. For a given shape and size of boom, this depends on Young's modulus E and the density d of the material. The "stiffness coefficients" E/d for some possible boom materials were tabulated for various woods, metals, and

plastics. Comparative sag tests were made on 20- and 30-ft. lengths of various commercial articles including aluminum irrigation tubing, fiberglass-reinforced epoxy-plastic well tubing, and timbers. It was concluded that booms of metal would sag least for their weight, and that the plastic would be inferior to wood in stiffness (despite its higher ultimate strength for equal weight). The low cost, easy replaceability and insulating ability of wood are decisive. Wood is apparently the best material available.

The best distribution of material, for a given weight, is in an openwork truss, since stiffness is proportional to the cube of the cross-section dimension. However, the expense and complexity of a 30-ft. long maple test truss which was made showed that solid softwood timbers would be more practical in lengths up to 20 ft., as well as more rugged. Greater lengths are impractical since stiffness is inversely proportional to the cube of the length. Both tests and theoretical considerations indicated that a square section would be the most stable shape easily available. Experiments led to the selection of 20-ft. redwood timbers 4 in. square, waterproofed with a drying oil, as the most practical structural unit. Modular 10-ft. lengths were selected for convenience in shipping. These may be joined end-to-end in pairs by means of light sheet-steel clamps consisting of two V-channels 1 ft. long, bolted together at the edges (Fig. 3). Experiment showed that $\frac{3}{32}$-in. thick mild steel is adequate for these clamps.

5. Fittings

Each dish-sled is driven at its center through a universal joint and a 2-in. tubular steel leg 2 ft. tall (Fig. 3). The leg and its two braces are bolted to flat steel tongues clamped under the ends of two of the booms by means of U-bolts. The universal joint is connected by a $\frac{5}{8}$-in. torsion-rod inside the tube to a cast aluminum steering handle at the top of the leg. This arrangement permits each sled to swivel in riding over bumps, yet to be steered with ropes if a keel is attached.

To permit free passage of the array over uneven surfaces, and to prevent the application of bending stresses to the booms and spars, the flat steel tongues clamped to the remaining boom ends are connected to their points of support through ball-and-socket joints (standard automobile-trailer hitches). The entire forward array pivots with respect to the weasel, to which it is linked by four trailer hitches. These are attached to a heavy, welded, five-sided yoke of 2 by 2 by $\frac{3}{8}$-in. angle iron which will fit around the front float of any type M29C weasel and is attached to the existing float-mounting bolts. The array may be either steered automatically with keels and steering-ropes tied to the yoke, or forced about rigidly with limit-ropes tied to the rear of the weasel. Both systems of ropes are shown in Fig. 3. Waxed $\frac{5}{8}$-in. nylon ropes are used to tow the rear sleds. Waxing or oiling of all ropes is necessary to prevent wetting and consequent electrical leakage between electrodes.

Field experience has shown that such an array of booms and sleds is practical and successful. It can be pushed over or along sastrugi, drifts, ruts, and rolling surfaces without difficulty. Without the towed sleds, it can be backed up or turned in a small circle (3). One unit is reported to have traveled over 1700 miles in the Antarctic, leading a tractor caravan into unexplored Marie Byrd Land and returning (4, 5). In the course of this trip, it traversed and "swept" a narrow lane 7 miles long, confined on both sides by crevasses, while following a tortuous, zigzag path (4).

However, the towed electrodes of the long system are comparatively difficult to maneuver, and are usable only during forward motion. They must be dragged back manually when traveling in reverse.

C. ELECTRICAL DESIGN

The electrical circuits employed in these crevasse-detectors will probably be discussed elsewhere in detail (6). However, the general design features will be outlined here. The first design step was a choice of values for the basic system parameters.

1. Operating Frequencies

Operating frequencies of 200 cps. or lower give the best crevasse indications ("anomalies") relative to background fluctuations (1). It is desirable to have at least two frequencies below 400 cycles, none of which is harmonically related to any other. It was found easy to provide a choice of 100, 150, 230 and 350 cycles in each of the two main systems, with 60- and 100-cycle emergency channels for the vibrator transmitters.

2. Power Level

This is determined by the friction-electric and other noise to be overcome. Friction-noise from the signal electrodes had, in Arctic field experiments, reached 0.2 volt rms. across 0.5 megohm with a 50-kc. pass band (1). This was expected to be reduced somewhat by the band-pass filters to be used. On the other hand, higher noise levels might be encountered below $-21°$ C. (the cryohydrate eutectic point). Therefore, a noise voltage of 0.2 volt was assumed.

To override this noise successfully, the normal signal e should be 2.0 volts at the electrodes. From 1955 field measurements, it was expected that this would require an input-electrode current I up to 10 milliamperes for the worst situation encountered (50-ft. spacings, 400 cycles); a system producing an electrode current of 10 ma. required an electrode voltage $E = 1000$ volts rms. on wet snow or 3000 volts on dry snow with 4-ft. square electrodes. Therefore, the required available level at the electrodes was taken to be 10 to 30 volt-amperes. The power factor of the electrodes was believed to be near zero except on wet snow. A maximum power capacity of 30 watts was therefore deemed ample.

The limited field experience available with the resulting equipment to date has indicated that the voltages now available may be inadequate when employed in conjunction with the 43-in. "dishpan" electrodes, because of their small bottom area. The high impedances of these electrodes apparently restrict the input current unduly. If the capacitance (through the snow) between the power electrodes and the leakage inductance of the transformer secondary could be adjusted in the field to resonance by means of a large additional series inductance, greater voltages (10,000 volts would not overload the insulation) and electrode currents probably could be obtained with present equipment. An added benefit would be improved matching to the power output transistors. At present, the latter must dissipate most of the available power as heat because of the predominance of capacitive reactance in the electrode load.

3. Circuit Isolation

The existence of any electrical path between the current circuit and the signal circuit, other than through the ice, must be scrupulously prevented. Even capacitive coupling between the wiring of the two electrode systems should be kept small in order to insure leakage reactances much greater than the electrode reactances. This can most easily be done by keeping the two circuits well separated in space, with energy sources, etc., contained in the electrodes themselves. It is particularly convenient for this reason to employ the observer himself or his vehicle as one electrode.

However, in a weasel-mounted system, it would be desirable to power everything from the weasel engine and battery for greatest reliability. This results from the fact that the weasel must run in any event, if the equipment is to function, and that additional engines or batteries riding on the electrodes frequently run out of fuel or charge, and are more subject to freezing and mechanical damage than are the weasel engine and battery. Antarctic experience to date corroborates this conclusion (**4**).

Furthermore, the observer and his indicating instruments should ride in the weasel. Therefore, energy should be exchanged with all the electrodes without introducing spurious alternating-current paths. Of two known successful methods of achieving this (**1**), magnetic coupling was selected for its greater ruggedness, simplicity, and economy of battery power. At the same time, the signal isolating transformers can be used to match the high signal-electrode impedances to the low-impedance transistorized signal amplifiers, and the power-isolating transformers can be employed to step up the output power from 12 or 24 volts at the transistors or vibrators to the required level of 1000 to 2000 volts at the current electrodes.

Both types of coupling transformers must have good insulation and

low capacitance between their primaries and secondaries. This is most easily achieved by spacing the secondary widely from the other parts (Fig. 5). The primary must be wound close to the core for efficiency. Split, balanced construction of the windings (so that their neutral central portions are nearest the core and around the outside, and the high-voltage ends are within the winding) is desirable. Such balanced construction reduces the voltage coupled by stray capacitance from the electrode leads of each winding to the other winding. In the signal transformers, the split secondary should be arranged in two parts so as to buck out interference from external magnetic fields (Fig. 5).

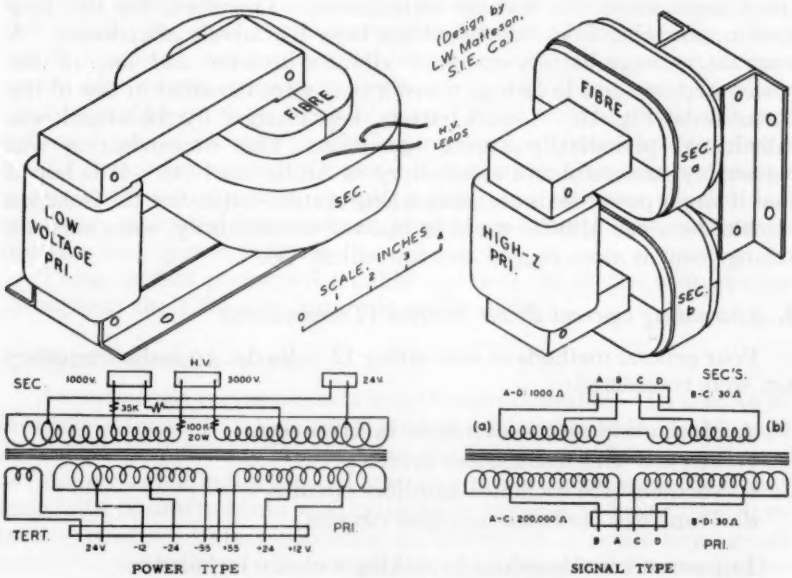


FIG. 5. Isolating transformer designs.

Isolating transformers meeting these requirements were manufactured to order by the Southwestern Industrial Electronics Company of Houston. The interwinding capacitances were kept below 65 mmfd. in both the signal and power types (38 mmfd. in Model 2). Rectangular, punched silicon steel cores (*E*-laminations with the center tongue removed) capable of handling 30 watts at 60 cycles were used throughout because of ready availability. Twenty-watt protective and current-regulating resistors of 35,000 ohms and 100,000 ohms, respectively, were installed in the 1000- and 3000-volt leads from the secondaries to the power-isolating transformers (in Models 2 and 2A only). These

were considered necessary to prevent possible burnouts from accidental short-circuits. Such an accident disabled a crevasse detector in Antarctica in 1956, which otherwise might have prevented a subsequent fatal fall into a crevasse (2). All transformers were installed in strong, weatherproof plywood cases fitted with AN connectors. A finished transformer, mounted under the upper boom, is visible in Fig. 3. A power transformer is also shown in Fig. 4.

The transformers have apparently been satisfactory in the wide system, but (in Model 1) did not provide sufficient isolation in the long system, using 43-in. sleds, probably because of the weaker signal available with increased electrode spacing (3), and because electrode impedances approached the leakage impedances. Therefore, for the long system, powering from the weasel has been tentatively abandoned. A separate, storage-battery-operated vibrator-inverter and one of the power step-up (and isolating) transformers were mounted in one of the power sleds (Fig. 4). A spare battery, kept charged by the weasel, was substituted periodically during operation. This improvisation was reasonably successful and satisfactory in Arctic tests (3). It is hoped that if larger power sleds are used, a long system employing the isolation transformers can also be made to operate satisfactorily, since such an arrangement is more rugged and convenient (4).

4. Alternating Current Power Sources (Transmitters)

Four general methods of converting 12 volts d.c. to audio-frequency a.c. were considered:

a. Mechanical motor-alternator inverter sets.
b. Vibrator-and-transformer inverters.
c. Vacuum-tube oscillator-amplifier circuits.
d. Transistor oscillator-amplifier circuits.

Important considerations in making a choice included:

1. High efficiency to conserve battery power, which may be vital to mobility and survival on the trail.
2. Frequency stability and sinusoidal waveform, to permit clean separation of the long and wide-system channels by means of filtering in the signal amplifiers.
3. Output voltage stability approaching 3 per cent, despite fluctuations of supply voltage of ± 1 to ± 8 volts (depending on temperature and battery condition) with weasel generator speed as the weasel is maneuvered.
4. Availability of several frequencies.
5. Reliability and long life.
6. Independence of temperature.

It was decided to use transistor circuits because of their efficiency, versatility, long life, ruggedness, good output waveform and frequency stability, and the possibility of incorporating enough negative feedback to insure good output regulation.

In the process of circuit development, however, it became apparent that while transistor circuits are indeed very good, present power transistors are easily damaged by overloads and are difficult to match to existing transformers. Consequently, auxiliary "emergency" vibrator-type sources also were provided, since these were readily and cheaply available in several frequencies.

The present main transmitters employ a transistorized, bridge-T oscillator circuit having degenerative feedback which provides good output stability for supply voltages varying between 12 and 32 volts. This circuit is operative at temperatures down to $-20°$ F., at which the necessary electrolytic condensers begin to freeze. The power amplifier (in Model 2A) employs a pair of type TN250 transistors in push-pull driving a pair of Delco type 2N174 power output transistors through a special low-resistance transformer. The theoretical maximum output power is 80 watts with a 24-volt supply, and the over-all electrical efficiency, estimated from tests on Model 1, is about 50 per cent with a resistive load (power factor = 1).

These circuits performed reliably and well (4) in the wide system throughout the 1700-mile Antarctic trip in 1956.

5. Signal Indication Means

An automatic crevasse-alarm was thought desirable. To achieve it, sensitive adjustable relays were needed. Special meter-relays (type 255), made by Assembly Products Inc. of Chesterland, Ohio, were chosen as primary signal indicators. These meters are $2\frac{1}{2}$-in., ruggedized and sealed, 1-ma. instruments with adjustable upper and lower limit-contacts. Positive contact operation is insured by a series locking-coil wound on the armature movement, and an external cycling and automatic release circuit. Through matched auxiliary relays, a 12-volt buzzer sounds and warning lights are caused to blink if the meter needle reaches either signal limit. The lower limit is used as a "fail-safe" warning of electrical faults in the apparatus, and the upper limit is used as a crevasse warning. Field tests have confirmed the convenience and usefulness of this means of indication (3). Figure 6 shows the double alarm-indicator box, which is shock-mounted in front of the driver of the crevasse-detector weasel. A headphone-jack outlet for the unrectified a-c. signal is provided on this box as a supplementary means of indication.

Several makes of visible-signal-recorders were considered. The best arrangement found, used in Models 2 and 2A, consists of two Texas

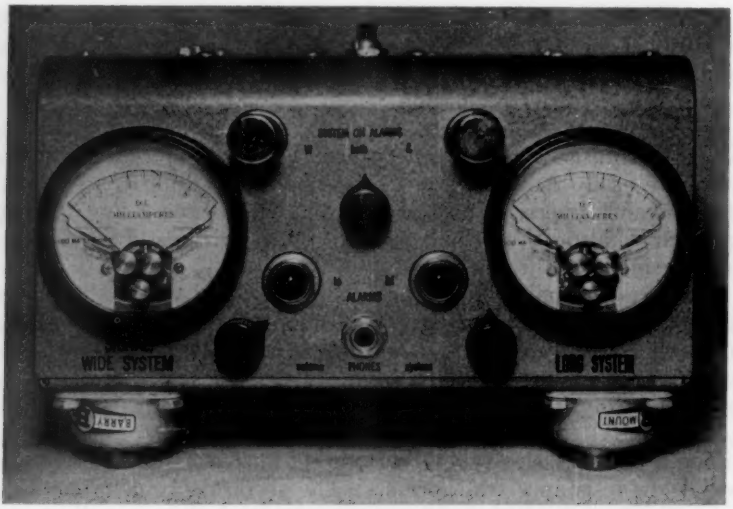


FIG. 6. Driver's signal indicators and alarms.

Instrument Company 1-milliampere, rectilinear-galvanometric ink-recorders mounted side by side. An externally-operated event-marker edge pen is provided on each. Several mechanical modifications were made. The writing tables were remounted at a 45° angle so that the record can be seen from the driver's seat. The paper-feed rolls are

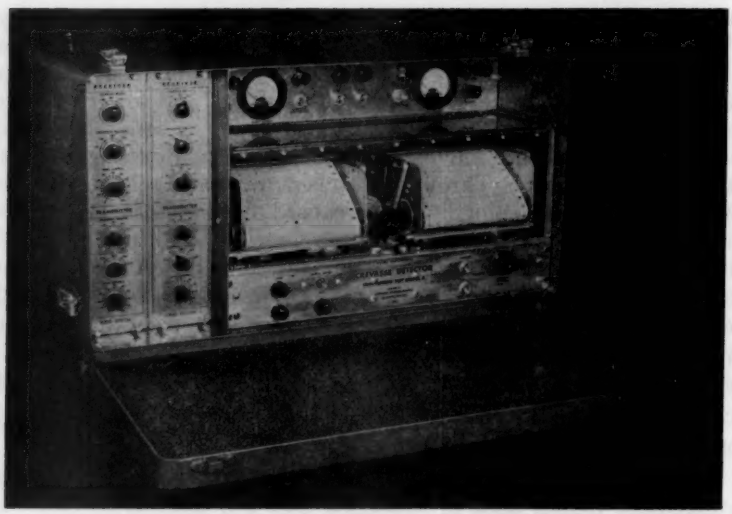


FIG. 7. Electronics cabinet, showing recorders (Model 2).

externally cable-driven from the weasel odometer drive through a duplexer fitting, a flexible cable and a multiple-ratio gearbox. The latter provides various choices of record resolution, ranging from $\frac{3}{4}$ in. of paper per mile traveled, to 1536 in. per mile. These machines, enclosed by a retractable lucite snow-shield, are shown mounted in the main electronics cabinet in Fig. 7. An outer, gasketed steel cover is provided for shipment and storm protection. All cable connections are made at the rear through rugged, waterproof AN connectors. The cabinet is shock-mounted above the weasel engine, on the driver's right. This equipment performed very well in the Antarctic and the operators found the recorders to be very helpful in the interpretation of the complex signal patterns (4).

6. *Over-All Operation*

Figure 8 is a block-diagram of the electrical system. The starting point may be considered to be the 12-volt battery of the weasel (near

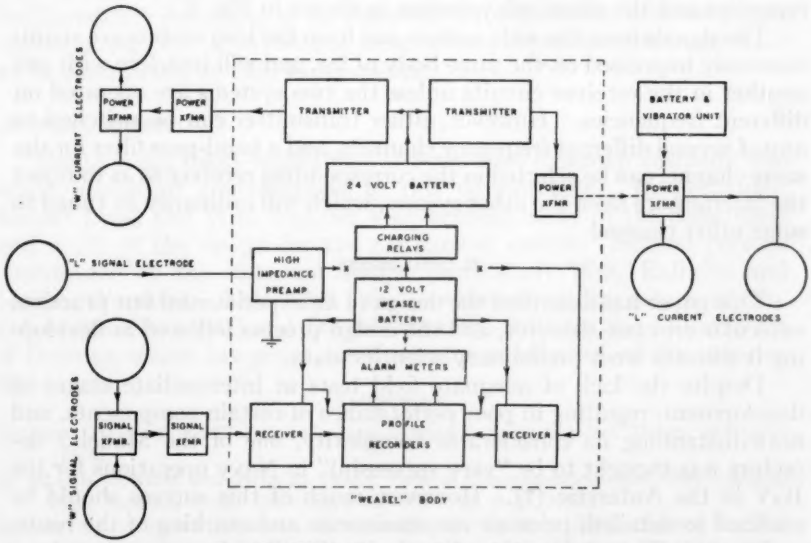


FIG. 8. Block diagram of electrical system.

center). This battery provides operating current directly to the two transistorized receivers, the recorder edge pens and paper-takeup-motor inverter, the alarm system, and to a charging circuit which supplies current to maintain a 24-volt storage battery. The 24-volt battery operates the oscillators and power amplifiers in the two main transmitters, one for the wide system and a spare (originally intended for the long system). Provision is made for operating the transmitters also

on the 12-volt weasel battery, at half their rated power. The alternating current generated by each transmitter is sent through two external isolation transformers in series to the power electrodes via sturdy rubber-covered, stranded-copperweld, seismograph-type cables (Vector Mfg. Co., Houston, type R3CWL-2-21). Alternatively, the isolated sled power unit (battery, heavy-duty vibrator and transformer) provides 3000 volts at 60 or 100 cycles to the long-system power electrodes.

The current patterns established in the ice by the two sets of power electrodes are sensed by the corresponding signal electrodes, each pair of which serves as an "antenna." The signal potentials generated in them are sent via seismograph-type cables to the main cabinet. In the wide system, two special external signal isolating and matching transformers in series are employed as shown in Fig. 8, but this is not necessary in the long system which is grounded to the weasel and employs instead an impedance-matching preamplifier. In the transistorized receivers, the two signals are filtered, adjusted to a convenient level by an attenuator, amplified by a fixed amount, rectified, and fed to the recorders and the alarm relay-meters as shown in Fig. 8.

The signals from the wide system and from the long system are simultaneously impressed on the same body of ice, and will interfere with one another in the receiver circuits unless the two systems are operated on different frequencies. However, either transmitter can be switched to any of several different frequency channels, and a band-pass filter for the same channel can be selected in the corresponding receiver so as to reject the interference from the other system, which will ordinarily be tuned to some other channel.

D. CONCLUSIONS

This paper has described the design of an experimental but practical vehicular crevasse detector, and the design process followed in developing it directly from preliminary scientific data.

Despite the lack of adequate field tests at intermediate stages of development, resulting in poor performance of certain components, and notwithstanding its considerable complexity, one of the Model 2 detectors was thought to be "very successful" in Navy operations for the IGY in the Antarctic (7). However, much of this success should be credited to detailed, prior air reconnaissance and marking of the route, and to coordinated detecting, blasting and bulldozing operations by a skilled and devoted team composed of electronics technicians, glaciologists and heavy-equipment experts (4).

1. Suggested Design Improvements

On the basis of the early field results, several improvements appear to be desirable in future models. In particular, larger electrode sleds would be expected to improve the electrical performance in several

respects and to result in more distinct crevasse anomalies. Electrode tuning should further improve the electrical efficiency.

It has also been suggested (8) that a simpler system employing a single electrical channel, meter and recorder could perform the functions of both wide and long systems: Connected as a highly maneuverable wide system, the equipment and supporting vehicles would first sweep the proposed trail to discover, mark and fill or detour around the thinly-bridged crevasses dangerous to light vehicles; if heavy vehicles were expected to follow, a second sweep could be made with the equipment arranged as a long system, to find and mark for filling any remaining crevasses.

The long system might be further improved by arranging it as a "Y" system (3, 8). In this arrangement, the four forward electrodes arranged in an arc are connected together in two groups, left and right. One or both groups, in conjunction with the weasel acting as the second signal electrode, may be connected to the receiver. Upon encountering a crevasse, the operator can determine its approximate strike direction by alternately switching in the right and left electrodes, with very little maneuvering (3). The merit of these several improvements would have to be determined by field experiments.

Acknowledgments

Credit is due many individuals at Southwest Research Institute who made important contributions to this development. In particular, Robert Doak and Wm. Van der Veer evolved many of the basic ideas and much of the design for the mechanical system. Several persons contributed to the electrical design, particularly Wm. Rollwitz and Joseph Wormser. This work was performed under contracts No. DA-44-009-ENG 2803 and DA-44-009 ENG-3003 for the Department of Defense, which has given permission for publication of this description.

REFERENCES

(1) JOHN C. COOK, "An Electrical Crevasse Detector," *Geophysics*, Vol. 21, pp. 1055–1070 (1956).

(2) SILAS B. BOWLING AND OWEN M. PERRY, Personal Communications; also "Electronics to Blaze Antarctic Trail," *Electronic Week*, Oct. 1, pp. 9–10 (1956).

(3) JOSEPH J. WORMSER, Personal Communication; also report to ERDL, "System Test Report for Engineering Test Model 1 Crevasse Detector." Contract DA-44-009-ENG-2803 (1956).

(4) PHILIP M. SMITH AND ROBT. W. ANDERSON, Personal Communication, 1957; also Antarctic Field Notes (abstract for publication in *Trans. Amer. Geophysical Union* now in preparation).

(5) WALTER SULLIVAN, "With the Trail Blazers in Antarctica," *New York Times Magazine*, Dec. 30, 1956, pp. 10–11, 31–32.

(6) WM. L. ROLLWITZ, "Transistorized Crevasse Detector Circuits for the IGY Antarctic Program" (approx. title). Probably to be published in *Electronics*.

(7) Associated Press Release: "Detector Beats Terror of Hidden Crevasse," Feb. 16, 1956.

(8) LYNN A. SMITHERMAN, ERDL, Personal Communication (1957).

Technique Developed to "Look over Pilot's Shoulder."—For many years the only accurate method of evaluating a pilot's performance was to have an instructor watch his actions from a second seat in the aircraft. The Air Research and Development Command (ARDC) has developed an observation method which allows personnel on the ground to view the action in airborne single seat jet interceptor aircraft—in essence, to "look over the pilot's shoulder."

Scientists at ARDC's Air Force Personnel and Training Research Center (AFPTRC) have developed a telemetry system which makes this possible.

Telemetry is the process by which the picture on the pilot's radar scope is radioed to the ground. It is accomplished by a series of high frequency radio signals. The signals received on the ground reproduce what is seen on the pilot's radar scope; thus, both the pilot and ground personnel have essentially the same picture.

ARDC scientists have found that their new telemetry system duplicates, with extreme accuracy and fidelity, the actual radar scope picture.

Installation of the newly-developed telemetry system in interceptor aircraft will result in better training for all-weather interceptor pilots. By means of telemetry, the pilot's instructor will be able, through voice communications, to instruct the student from the ground. In addition, the ground reproduction of the pilot's radar scope face will aid the instructor in measuring the student pilot's performance, thereby providing a medium for improving the training of all-weather interceptor pilots.

AFPTRC's Interceptor Pilot Research Unit conducted all phases of the telemetry experiment in the F-86D aircraft, but the experiment may also be adapted for use in jet aircraft of the current century series, such as the F-102.

Automatic Silicone Lubricator.—The manufacturers of FilMagic Silicone products (FilMagic Cloth and FilMagic Tapes) are marketing a new device for automatic silicone lubrication of recording tapes and motion picture films.

The FilMagic Pylon is a windowed acetate tube filled with silicone-impregnated FilMagic Cloth. After activating the filler by means of a silicone fluid, the lubricant is fed in controlled amounts through a sleeve of FilMagic Cloth onto the tape or film. The Pylon is mounted between feed reel and reproducing parts of equipment for continuous performance while the machine is operating.

It is claimed that the FilMagic Pylon is the first practical application of an accepted principle of silicone lubrication, which acknowledges that lubrication is most effective when applied close to the point of use.

"Point-of-Use" lubrication-protection results in better sound reproduction, reduction of "wows," less head wear, and smoother, cooler operation according to the manufacture.

FilMagic Pylon kits are supplied either with suction-cup Pylons, or with Pylons equipped with a flange-type mount which can be installed permanently on most equipment.

Each Pylon kit contains one of the Pylons, a plastic squeeze-bottle of FilMagic silicone Re-Loader, and six sleeves of FilMagic Cloth. Complete instructions for installation and use are furnished in each kit, which measures only 3 by 3 in.

Further details may be obtained from the manufacturer, The Distributor's Group, Inc., 204-14th. Street, N. W., Atlanta 13, Georgia.

DETERMINATION OF RIFLE TRAJECTORIES

BY

HOMER S. POWLEY[1]

INTRODUCTION

A comparatively small amount of data has ever been published concerning rifle and other small arms trajectories. Experimental methods of determination can be somewhat costly and most of the results cannot be considered to be of general application. Theoretical methods can have general application but are often times somewhat difficult and furthermore seem to lack the "authority" of actual firings. Theoretical methods revolve around calculations of drop below a line of departure and experimental methods are with reference to drop referred to a line of sight. No acceptable method of accurately determining where the line of sight is with reference to the line of departure has been proposed up till now. Such a method will be described together with some new information concerning theoretical methods. Extension of experimental data from two points with reference to a line of sight and without knowledge of velocities and ballistic coefficients will be discussed. Trajectories at great distances or at extreme range cannot be included here.

THEORETICAL METHODS

One of the oldest methods for trajectory determination, the Siacci Method (and as employed by Ingalls (1)[2]), has a new application in the form of the Speer Ballistics Calculator published by Speer Products Company, 1023 Snakeriver Avenue, Lewiston, Idaho. It is an inexpensive but well made slide rule which not only enables one to rapidly calculate drop below line of departure but also remaining velocities for the whole class of modern rifles. The ballistic coefficients used are based on a projectile with a 2-caliber radius of ogival head; this is variously referred to as the Mayeveski, Zaboudski, Ingalls, British "Old" or Gavre projectile.

Theoretical, or ballistic table, methods vary to a great degree in difficulty according to the nature of the air resistance experienced by projectiles of differing shape. Show in Fig. 1 are the results of practically all of the available published information concerning the drag of different shapes of projectiles in use. The *retardation*, or *drag*, is expressed in feet per second per second, of *standard projectiles* which are one inch in diameter with a *mass* of one pound, but of differing shapes. The drag of other *sizes* is proportional to the reciprocal of the *sectional*

[1] Technical Service, The Harshaw Chemical Company, Cleveland, Ohio.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

density. Sectional density is expressed in units of pounds per inch (of diameter) squared. For example, a projectile of 0.25 lb. and 1.0-in. diameter has a sectional density of 0.25 and the drag is four times the illustrated value for a particular shape.

We have brought together here some very widely scattered information which is difficult to obtain. Following is the customarily used terminology which relates the various functions as variously found in the literature.

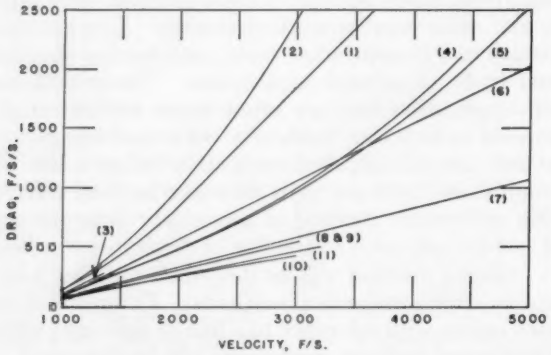


FIG. 1. Drag, feet per second per second, of various Standard Projectiles as a function of velocity in feet per second. Curve numbers are identified in text.

The G-Function, $G(v)$ = Drag/Velocity

Sometimes there is desired a value for the *function of velocity* (a constant below 800 f/s), also designated as $B(v)$ = *retardation coefficient*,

$$K(v) = \text{Drag}/(\text{Velocity})^2 = G(v)/\text{Velocity}.$$

For the Standard Projectile, the *drag coefficient*,

$$K_D = \text{Drag}/0.0005217(\text{Velocity})^2 = 1916.7 \cdot K(v).$$

The drag coefficient is dimensionless. Drag/32.16 = air resistance in *pounds* (sometimes referred to as drag in force units).

The numbering of the curves in Fig. 1 corresponds to the following numbered paragraphs which describe most of the available literature:

(1) Computed from F. Bashforth's data given on p. 394 ff. in Great Britain War Office's "Textbook of Small Arms," 1929. These represent data obtained with an electric chronograph in 1866 in England. Below 250 f/s the values may be computed from the formula

$$\text{Drag} = 0.00009 \cdot V^2.$$

(2) Values for 800 f/s and upwards are computed from those given by K. Becker and C. Cranz in *Artilleristische Monatshefte*, Vol. 69, p.

189 (1912) and Vol. 71, p. 333 (1912). The determinations were made with a projectile of 8-mm. caliber, square at both ends. Below 800 f/s the values may be computed from 0.0000845 V^2.

(3) These values are computed from the table given on p. 55 of Dr. Charles S. Cummings' "Everyday Ballistics," 1950. They were obtained with a 40 grain .22-caliber bullet with a head 1.06 bullet diameters high of parabolic shape. Note that the height of head is very close to the Krupp normal (standard) projectile given in (4) and that the drag is approximately the same even though the Krupp determinations were made with a 4-in. artillery projectile. Dr. Cummings is one of America's foremost ballisticians.

(4) These values are computed from those obtained by O. von Eberhard of the German Krupp firm with a 10-cm. artillery shell, given by Dr. C. Cranz and Capt. K. Becker in "Handbook of Ballistics," Vol. I (Exterior Ballistics), second edition, 1921. The Krupp normal (standard) shell (projectile) has a head which is 1.08 diameters high, an ogival radius of 2 diameters and a flat front (meplat) of 0.36 diameters.

(5) These values are taken from "Range and Ballistic Tables, 1935" by E. E. Herrmann. The French Gavre Commission assembled these values to apply to an ogival projectile similar to the Mayeveski projectile fired by Krupp at Meppen, Germany in 1881. The Mayeveski projectile had an ogival radius of 2 diameters for a head which was 1.32 diameters high. This is the same projectile used as the basis for tables by Ingalls. The experimental program was conducted in 1888.

(6) At the request of the French Gavre Commission, M. J. Dupuis, Chief Engineer of the Naval Artillery, conducted an experimental program for the revision of Air Resistance laws from 1921 to 1923. The research was described by him in *Memorial de l'Artillerie Française*, p. 613 (1928). The resistance functions themselves are found in *Annexe au I^er^ fascicule de Memorial de l'Artillerie Française*, 1929, Table B, "Fonctions empiriques de la resistance de l'air." The values given here are taken from a graph of the function given by Oberst Paul Curti, "Einführung in die Aussere Ballistik," p. 107, Huber and Co. Aktiengesellschaft, Frauenfeld, Schweiz (1945) and are for the "old" type of projectile with 1.00 diameter height of head.

(7) Taken from the same source as in (6) above but the values apply to Dupuis' "new" projectile which has a 2.00 diameter height of head, 4.25 diameters radius of rounding.

(8) The values given are computed from the velocity-range table given on p. 332 of Great Britain War Office's "Textbook of Small Arms," 1929. The data given therein were obtained with a .303 Magnum bullet, weight 175 grains, with Spitzer point. A ballistic pendulum was used for the velocity determinations and these are considered to be quite accurate.

(9) These values were converted from the metric values given by the world's pre-eminent ballistician, Dr. C. Cranz, in the 1912 issues of

Artilleristische Monatshefte referenced in (2) above. The determinations were made with an 8-mm. Spitzgeschoss (pointed shot) or Spitzer bullet which is a projectile with a head which is 2.55 diameters high having an ogival form of radius 8 diameters and a flattened point (meplat) of 0.15 diameters. Values below 800 f/s may be computed by British determinations given in Table I of Appendix 6 in "Textbook of Small Arms" reference in (1) above.

(10) These values were computed from the same source given in (8) above and are for a .303 caliber bullet of the same form and weight, except that this bullet has a boat-tail. Note that these values are in close agreement with those obtained from an artillery sized projectile given in (11) below.

(11) These values are computed from those given on p. 430 of Col. Thomas J. Hayes' "Elements of Ordance," 1938. The type "J" projectile is long-pointed and boat-tailed.

Please notice curve No. 6 of Fig. 1 where the function is given for Dupuis "Old." The change of drag with velocity does not agree very well with the original Gavre determinations. This throws considerable doubt on the original Gavre values. Two World Wars have been fought by several nations who used the older Gavre functions very extensively. At any rate, these newer determinations for older, more blunt, projectiles seem to be an excellent approximation to a straight line above the velocity of sound. Also this is true for the Dupuis "New," both Hodsocks, Cranz Spitzer and the "J" Projectile. In this same region the round ball and cylinder are very close to obeying the Quadratic Law.

To better visualize the importance of change of shape and to follow a previous graphic example (2), Fig. 2 calculates the distance in yards travelled by a 180-grain bullet in .30 caliber if only the shape is varied and the muzzle velocity is 3000 f/s with a remaining velocity of 1500

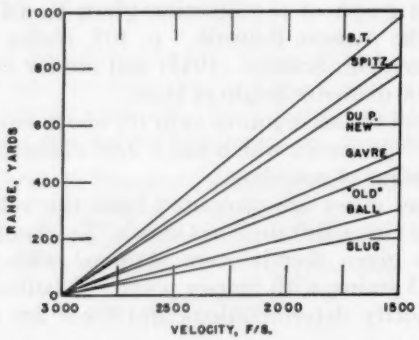


FIG. 2. Range in yards of 180 grain, .30 cal. bullets of various shapes when starting at 3000 foot seconds velocity and terminating with 1500 foot seconds velocity.

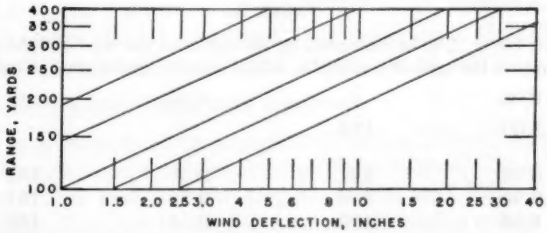


FIG. 3. Relative wind deflections in inches for ranges between 100 and 400 yards.

f/s. This velocity range covers most of the important uses of military and sporting rifles.

The inclusion of the round ball is to illustrate the shape effect hypothetically since 180 grains weight of any known material could not be contained in the space. The calculations were all done by simple methods of numerical integration.

Hardcastle (3) as long ago as 1913 commented on the linear relationship of drag to velocity. In a previous paper (4), the author showed that the assumption of a linear relation for the Spitzer bullet not only simplified ballistic calculations but that the drop below line of departure was proportional to the 2.3 power of the range. Additional calculations now show that with the above shapes which are also linear the drop is proportional very closely to the 2.3 power. Obviously this extends the approximations to include all the shapes mentioned with the exception of ball and cylinder. We will make use of this point a little later.

The author (4) also showed that for a limited range the wind deflections were proportional to the 2.15 power. Calculations now show this to have more general application. Figure 3 has been calculated on this basis and should prove to be useful.

Figure 3 is only on a relative basis. If the amount of wind deflection is known at a range, moving parallel or with one of the slanting lines gives the wind deflection at the indicated ranges. If the wind has blown the bullet experimentally 14 in. at 300 yd. and there is no change in the wind, the same wind can be expected to have moved the bullet 26 in. at 400 yd., 5.9 in. at 200 yd. and 1.3 in. at 100 yd., for example.

A new ballistic table method for determination of drop has recently been described by McShane, Kelley and Reno (5). A factor, f, is tabulated as a function of the ratio of the remaining velocity, V, to the muzzle velocity, V_0. The factor is multiplied by the square of the time of flight in seconds. Table I gives this factor in units such that the drop is determined in inches. It develops that the drop is vertical and independent of the angle of the line of departure so this table is particularly convenient to use.

EXPERIMENTAL METHODS

In the past it was a matter of great convenience for the author to calculate the difference in drop betweeen 100 and 400 yd. This can be

TABLE I.

Multiplying factor, f, to be multiplied by the square of the time of flight which corresponds to the ratio of terminal to initial velocity, giving drop in inches.

V/V_0	f	V/V_0	f
1.00	193		
0.98	192	0.58	162
0.96	191	0.56	161
0.94	190	0.54	160
0.92	187	0.52	157
0.90	186	0.50	156
0.88	185	0.48	154
0.86	184	0.46	152
0.84	182	0.44	150
0.82	181	0.42	148
0.80	180	0.40	145
0.78	178	0.38	144
0.76	176	0.36	142
0.74	175	0.34	139
0.72	174	0.32	137
0.70	172		
0.68	170		
0.66	169		
0.64	167		
0.62	166		
0.60	164		

done by knowing the ballistic coefficient and the muzzle velocity. The values can be compared with the results of experimental shooting thus furnishing correlations. When determining the drop difference between two ranges, the relationship between the line of sight and line of departure is constant and therefore need not be considered when the difference is measured by firing. 100 and 400 yd. were selected as practical and obtainable ranges which could still exhibit significant results. Obviously, from the theoretical standpoint greater range differences would be desirable.

The following directions were followed:

To determine the 100/400 drop, fire at the two ranges to determine the impact difference (in inches) between the two ranges. Increase this value by three times the height of the sight line above the bore *plus* three times the 100-yd. height of impact over aim (*minus* if the impact was below 100-yd. aim). The total of the figures gives the distance of the 400-yd. point of impact below an extension of a line drawn from the muzzle through the 100-yd. point of impact. This value is referred to as the 100/400 yard drop. Dividing by 4.19 (or multiplying by 0.239) gives the *difference* in angles of departure in minutes between 100 and

400 yd., that is, the "minutes up from 100." It happens that when bullets which follow the 2.3 relationship are being used, the 100/400 drop equals one-half the drop below line of departure at 500 yd.

The following suggestions were observed:

The rifle is preferably to be adjusted to have a 100-yd. zero, although it is not necessary except as a matter of convenience. It is to be fired from a comfortable rest and the targets at 100 and 400 yd. should be arranged so that they can be fired at alternately with a minimum change of shooting position. Inspection of Table II will show that the 400-yd. target should have ample extra paper below the aiming point, upwards of 24 in. in most cases. One or two fouling shots should be made (perhaps for a rough check of the zero) before firing the sequence. It is important that the longer 400-yd. range be accurately measured since the drop is changing rather rapidly there.

The shooting should begin at 400 yd. with one shot. The second shot should be made at 100 yd., the third shot at 400 yd., and so on,

TABLE II.

High velocity trajectories showing inches of impact below line of aim starting with 100-yd. zero and line of sight 1.5 in. above bore line.

100/400	Range in Yards							
Drop	150	200	250	300	350	400	450	500
15	0.0	0.8	2.0	4.2	6.8	10.5	15.	20.
16	0.0	0.9	2.2	4.6	7.5	11.5	16.	22.
17	0.0	1.0	2.5	5.0	8.2	12.5	17.	24.
18	0.1	1.2	2.8	5.6	8.9	13.5	19.	26.
19	0.1	1.4	3.0	6.0	9.3	14.5	20.	28.
20	0.2	1.5	3.2	6.5	10.4	15.5	22.	29.
21	0.3	1.6	3.3	7.0	11.1	16.5	23.	31.
22	0.4	1.8	3.6	7.4	11.9	17.5	24.	32.
23	0.4	1.9	4.0	8.0	12.5	18.5	26.	34.
24	0.4	2.1	4.2	8.4	13.2	19.5	27.	36.
25	0.4	2.2	4.7	8.6	13.9	20.5	28.	38.
26	0.5	2.4	5.0	8.9	14.6	21.5	30.	39.
27	0.6	2.6	5.2	9.4	15.4	22.5	31.	41.
28	0.6	2.7	5.6	10.3	16.0	23.5	33.	43.
29	0.7	2.8	5.8	10.8	16.7	24.5	34.	45.
30	0.8	3.0	6.1	11.2	17.5	25.5	35.	47.
32	0.8	3.3	6.6	12.2	18.9	27.5	38.	50.
34	0.9	3.6	7.2	13.2	20.3	29.5	40.	53.
36	1.0	3.9	7.7	14.1	21.7	31.5	44.	57.
38	1.1	4.2	8.5	15.0	23.2	33.5	46.	60.
40	1.2	4.5	8.8	16.0	24.6	35.5	49.	64.
42	1.3	4.8	9.4	17.0	25.9	37.5	51.	67.
44	1.4	5.1	9.9	17.9	27.3	39.5	54.	71.
46	1.4	5.4	10.6	18.9	28.9	41.5	58.	74.
48	1.6	5.8	11.0	19.8	30.2	43.5	60.	78.
50	1.6	6.0	11.6	20.8	31.6	45.5	62.	81.

alternating between 100 and 400. The final shot should be made at the same range as the first shot. This procedure is recommended because there will be some heating of the gun and it will have a different point of impact for each temperature. If the gun is quite accurate, this change of impact may be quite negligible, but even so one should take the precaution of firing an even number of shots at one target and an odd number at the other.

Suppose, for a simple numerical example, that the temperature of the gun was 60° for the first shot, 65° for the second, 70° for the third, 75° for the fourth and 80° for the fifth. Simple calculation shows that the average temperatures for the odd and the even are each 70°.

The gun should be permitted to cool somewhat between each shot since a change of powder temperature of any importance due to placing a cartridge in a hot gun chamber will cause a significant change of muzzle velocity and this method assumes the muzzle velocity to be about constant. Needless to say, all of the other precautions common to group shooting from a rest should be taken.

For a gun which usually shoots with minute of angle accuracy, or better, five shots should be sufficient at 400 yd. Other guns may require nine or eleven shots for the satisfactory establishment of a center of impact. The 400-yd. shots will be quite scattered and perhaps enough so that the center of impact may be in question.

The following procedure is correct for the determination of the location of the center of impact.

Draw a horizontal line through the highest shot of the group and measure the vertical distance of each shot from this line. Average and draw a line below the first line at this average distance. The distance from this latter line vertically to the aiming point gives the distance above or below aim. Include the zero distance of the shots through which the reference line was drawn in determining the average distance.

Table II has been assembled to cover drop below line of sight in inches with the condition that the line of sight is $1\frac{1}{2}$ in. above the muzzle. If the table is required to be used with other sight distances, the geometry is simple. If the 100/400 drop has been determined by ballistic table methods, Table II immediately gives the complete trajectory to 500 yd.

For the condition that a bullet is being used which follows the 2.3 relationship Table II is unique in that a complete 500-yd. trajectory is known as soon as the drop below line of sight is determined at one of the tabulated distances and probably with as good accuracy as the determination really was. For this use one reads only horizontally on the line where the datum fell. Since the table is made for a 100-yd. zero, two points on the trajectory have really been determined. Other ballistic quantities are not required to be known.

Trajectory information published by United States ammunition

manufacturers show the 100/400 drop figures to range from 27 in. for the .220 Swift cartridge through 36 in. for the .30–06 to 50 in. for the .30–40 Krag. Experimental firings of non-standard cartridges done by the author gave 100/400 drop figures ranging from 23 in. for a .270 Magnum through 33 in. for a .22 Wasp to 47 in. for a version of the .257 Roberts.

Dr. Mann (6) was one of the few who were able to effect drop measurements free from objection but then only with an occasional "gilt edge" barrel where the impacts did not vary with the orientation of the barrel in his special mechanical rest. He did not report many measurements, however. Following is a method of experimental determination of drop below line of departure which has been satisfactorily used for artillery and involves shooting through three equi-distant paper targets. Figure 4 illustrates the arrangement. The mathematics is derived from Lagrangian interpolation formulae.

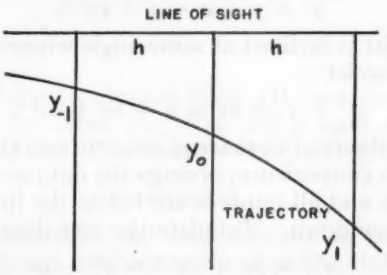


FIG. 4. Notation for drop of trajectory below line of sight at equi-distant ranges.

The problem revolves around finding the angle between the line of departure and the line of sight. We now give the method for determining this angle. Let impacts, y_{-1}, y_0 and y_1 be determined below the line of sight along x at equal distances, h. Then,

$$\tan \phi = \frac{-1.5y_{-1} + 2y_0 - 0.5y_1}{h}$$

where ϕ is the angle at x, y_{-1}.

If the height of sight line is subtracted from y and $y_{-1} = 0$,

$$\tan \phi = \frac{2y_0}{h} - \frac{y_1}{2h}$$

where ϕ is the angle at the muzzle.

The method assumes the trajectory to be a section of a simple parabola.

First the determination of drop with relation to line of sight is made, then line of sight is related to line of departure when the angle is determined. Bore-sighting can be related to either but the bore-sight is affected by droop of the barrel. If droop is separately determined, then the "jump" of the barrel prior to projectile departure becomes known.

The preceding can be successfully used with low-velocity rifles, pistols and the like. Attempted applications to high velocity rifles result in many anomalies.

Finally we are proposing a new method for the experimental determination of drop below line of departure. This involves shooting at a minimum of four equi-distant ranges. The derivation and procedure follows.

Assume drop below line of departure for bullets,

$$y = cx^{2.3} \tag{1}$$

where c is a constant, x is the range and y is the drop below line of departure.

For calculation convenience, assume drop values of y are positive.

With reference to a higher line of sight, let

$$y' = y + a = a + cx^{2.3}. \tag{2}$$

The line of sight is inclined at some angle whose tangent is b to the line of departure, so let

$$y'' = y' + bx = a + bx + cx^{2.3}. \tag{3}$$

y'' is then the observed distance of impact from the line of sight.

For calculation convenience, arrange the data so that x is in tens or hundreds of yards and all impacts are below the line of sight, that is, swing the trajectory down. Tabulate the new data. Next, let

$$y''' = bx + cx^{2.3} = y'' - a \tag{4}$$

that is, tabulate in the next column of y''' by subtracting the height of the sight line from y''. Next, let

$$y'''' = \frac{y'''}{x} = b + cx^{1.3}. \tag{5}$$

Tabulate in the next column by dividing each of the values of y''' by the corresponding values of x.

Now select from the table three related points (y_1'''', x_1), (y_2'''', x_2) and (y_3'''', x_3) such that

$$x_2 = (x_1 \cdot x_3)^{0.5}. \tag{6}$$

x values of 1, 2 and 4 will satisfy this condition. Now calculate the value of b.

$$b = \frac{y_1 \cdot y_3 - y_2^2}{y_1 - 2y_2 + y_3}. \tag{7}$$

b is the tangent of the angle of slope which the line of departure makes with the line of sight after the trajectory was swung.

Tabulate next the values of $(y'''' - b)$, observing the sign of b, by subtracting b from y''''.

In the next column, tabulate $(y'''' - b) \cdot x$ which gives the values of y, the drop below the line of departure.

Plotting $\log y = f(\log x)$ will serve as a check on the original assumption of Eq. 1.

TABLE III.—*Sample Calculation of Drop.*

Range, yd.	Impact Low, in.	x	y''[1]	y'''	y''''	$y''''-b$	(Drop) y
0	1.5	0	1.5	0.0	0.0	1.2	0.0
100	0.0	1	2.0	0.5	0.5	1.7	1.7
200	3.0	2	7.0	5.5	2.8	4.0	7.9
300	11.2	3	17.2	15.7	5.2	6.4	19.3
400	25.5	4	33.5	32.0	8.0	9.2	36.8
500	47.0	5	57.0	55.5	11.1	12.3	61.5

$$b = \frac{0.5 \cdot 8.0 - (2.75)^2}{0.5 - 2 \cdot 2.75 + 8.0} = \frac{4.0 - 7.56}{8.5 - 5.5}$$

$$b = -1.2$$

[1] Trajectory swung 2 inches per one hundred yards.

A sample calculation is given in Table III based upon an experimental firing reported by Ness (7). The bullet used would have a coefficient of form of about 0.8 referred to the Gavre (Ingalls) function.

CONCLUSION

Up-to-date air resistance and drop information has been presented. Furthermore a proposed method for the experimental determination of drop below line of departure has been explained. It should be recognized that this method is based on the assumption of an approximation in the form of an empirical formula for drop. It is believed that whatever errors exist in the approximation are of a smaller order of magnitude than the ordinary errors of measurement. All of the data collected by the author indicate this to be the case but experimental determinations by others will have to be made before such proposals can be considered to have been verified.

In any event, progress has been made in the refinement of theoretical methods and in their relation to practical measurements.

REFERENCES

(1) JAMES M. INGALLS, "Ingalls' Ballistic Tables," Artillery Circular M, Government Printing Office, Washington, D. C., 1918.
(2) PETE KUHLOFF, *Argosy*, November, 1953, p. 51.
(3) J. H. HARDCASTLE, *Arms and Explosives*, June, 1913, p. 86.
(4) HOMER S. POWLEY, JOUR. FRANKLIN INST., Vol. 257, p. 221 (1954).
(5) E. J. MCSHANE, J. L. KELLEY AND F. V. RENO, "Exterior Ballistics," The University of Denver Press 1953, p. 279.
(6) FRANKLIN W. MANN, "The Bullet's Flight," Huntington, W. Va., Standard Printing and Publishing Co., 1909.
(7) F. C. NESS, "Practical Dope on the Big Bores," Harrisburg, Pa., Stackpole and Heck, Inc., 1948, p. 119.

Semiconductor Diode Provides Gain as Converter.—Useful amplification in a semiconductor diode converter stage has been proven feasible by scientists at Bell Telephone Laboratories. Working with gold-bonded germanium diodes and with diffused P-N junction silicon diodes, A. Uhlir, Jr. and A. E. Bakanowski of Bell Laboratories have achieved significant amounts of gain both in up-converter and down-converter stages.

Most promising results to date have been obtained with the up-converter, in which a low frequency is converted to a higher frequency. Gains as high as 6 db. with adequate bandwidth for most applications have been achieved with gold-bonded germanium diodes when converting from 75 to 6000 mc. Such a converter stage is useful as a modulator for a microwave transmitter. These up-converter amplifiers are essentially unilateral—that is, they do not amplify in the reverse direction and so an amplifier stage employing such a converter is very stable.

Using the diffusion process which was developed at Bell Laboratories, diffused silicon P-N diodes have been made which exhibit conversion gain and are usable at higher temperatures than germanium diodes.

An outstanding feature of the up-converter diodes is that they can be made with relatively large active areas, thus greatly increasing their power-handling capacity over that of conventional point-contact converters.

The new TH microwave radio relay system recently announced by Bell Laboratories employs gold-bonded germanium diode up-converters. One application is the transmitting modulator, used to convert the intermediate frequency (60 to 90 mc.) to the frequency of the final output (various frequencies in the 6 kmc common carrier band). This stage is operated at zero gain in order to provide the required bandwidth (10 mc. ± 0.05 db).

Other up-converter stages combine amplified harmonics of a highly stable crystal oscillator to give the various desired carrier frequencies in the 5925 to 6425 mc. band. In this application, up to 10 db. of gain is realized since bandwidth is not a problem.

These uses represent the first practical applications of diode converters in which there is no loss of signal in the converter stage.

Conversion gains as high as 45 db. have been achieved in down-converters using diffused silicon diodes. Also, M. E. Hines has demonstrated a negative-resistance diode amplifier operating at 6000 mc. Such amplifiers and down-converters in general are regenerative; that is, there is poor isolation between input and output. In the past this has limited their usefulness, but the availability of nonreciprocal ferrite devices may improve considerably the feasibility of regenerative operation of diode amplifiers and amplifying down-converters.

THE EFFECT OF A VARIABLE EVAPORATION RATE ON THE BALLISTICS OF DROPLETS *

BY

C. C. MIESSE [1]

ABSTRACT

In order to allow for the effect of the variation of evaporation rate of a liquid droplet with its Reynolds number on its velocity and diameter variations, the present analysis considers the ballistics and evaporation (Frössling's) equations simultaneously. The resultant nonlinear equation yields analytical solutions for discrete values of the viscosity to still air evaporation rate parameter, which permit ready determination of the variation of drop size and relative velocity with time or distance. The results indicate that the constant evaporation rate analysis is valid for large values of the parameter mentioned above, but should be modified for smaller values. Numerous illustrative curves are presented, and the analysis is applied to available experimental data.

NOMENCLATURE

$A = 0.3\ (Sc)^{\frac{1}{3}} \sqrt{|U_0 - V_0|\ (D_0)/\nu}$
a = constant acceleration
$B = [1 + AW/(1 + 2q_0)]\ W^{1/2\ q_0}$
$b = 1/2q_0$
$C = [W + (1 + 2q_0)/A]\ W^{1/2\ q_0}$
D = droplet diameter
D_0 = initial droplet diameter
$f = -\ dw/d\theta$
$k = 18\eta/\rho'$
L = total distance of droplet travel
$p = \phi^{\frac{1}{2}}$
$q_0 = k/\lambda_0$
$R = |U - V|\ (D)/\nu$, Reynolds number
$Sc = \nu/\mathfrak{D}$, Schmidt number of vapor
T = droplet lifetime
t = time
U = air velocity
U_0 = initial air velocity
V = droplet velocity
V_0 = initial droplet velocity
$W = \sqrt{1 - V_0/|U_0 - V_0|}$
$w = \sqrt{1 - V/|U_0 - V_0|}$
x = distance of travel
$y = \sqrt{D/D_0}$
$Z = W^{1+1/2\ q_0}$
$z = w^{1+1/2\ q_0}$
η = dynamic viscosity of air
$\Theta = kT/2D_0^2$
$\theta = kt/2D_0^2$
λ_0 = evaporation rate in still air
ν = kinematic viscosity of air
ρ' = density of droplet
$\phi = f \cdot (w)^{2/q_0 - 1}$
$\mathfrak{D}$ = diffusion rate of vapor

INTRODUCTION

The problem of droplet ballistics has been investigated both experimentally and theoretically by many authors. Fledderman and Hansen (1)[2] studied the effect of turbulence on the velocity and vaporization of droplets, and concluded that the drag coefficient varies inversely as the three-halves power of the Reynolds number. Further experimental

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

studies were made by Ingebo (2, 3), whose first report indicated that the drag coefficient varied inversely as the relative velocity, this variation being modified in the second report which concluded that the drag coefficient varies inversely as the 0.84 power of the Reynolds number. The ballistics of droplets has been studied theoretically by Langmuir and Blodgett (4) who neglected the evaporation process; Hughes and Gilliland (5), who stressed the importance of an acceleration drag; Ingebo (2), who solved the evaporation and momentum equations simultaneously by numerical integration; and Miesse (6), who assumed a constant evaporation rate and Stokesian flow.

Since none of these analyses produced an analytical solution for the problem which includes the mutual effects of velocity and evaporation rate, the present study was undertaken in order to obtain a solution which would satisfy both Frössling's (7) evaporation equation

$$\frac{d(D^2)}{dt} = -\lambda_0(1 + 0.3\sqrt[3]{Sc}\sqrt{R}) = -\lambda_0\left(1 + 0.3\sqrt[3]{Sc}\sqrt{|U - V|(D)/\nu}\right) \quad (1)$$

and Miesse's ballistics equation, which was found to be valid for Ingebo's experimental velocity data (8):

$$\frac{dV}{dt} = a + \frac{k(U - V)}{D^2}. \quad (2)$$

Although the previous ballistics analysis, which neglected the variation of evaporation rate with Reynolds number, yielded analytic solutions of Eq. 2 for all variations of U which were linear with distance, the results of the present investigation include simultaneous solutions of Eqs. 1 and 2 only for zero acceleration ($a = 0$) and constant values of the air velocity ($U = U_0$).

ANALYSIS

With these simplifying limitations, inspection of Eqs. 1 and 2 reveals the presence of the two dependent variables, D and V, both of which are functions of the independent variable t. For the purpose of obtaining more general solutions, the following dimensionless variables are defined:

$$w^2 = 1 - V/|U_0 - V_0|, \; W^2 = 1 - V_0/|U_0 - V_0| \quad (3)$$

$$y^2 = D/D_0 \quad (4)$$

and

$$\theta = kt/2D_0^2 \quad (5)$$

where V_0 and D_0 are the initial values of V and D, respectively.

Substitution of Eqs. 3, 4, and 5 into Eqs. 1 and 2 yields the following

dimensionless representation,

$$\frac{dy^4}{d\theta} = -\frac{2}{q_0}[1 + Awy] \tag{1a}$$

and

$$\frac{dw}{d\theta} = -\frac{w}{y^4} \tag{2a}$$

respectively, where $A = 0.3\sqrt[3]{Sc}\sqrt{|U_0 - V_0|D_0/\nu}$ and $q_0 = k/\lambda_0$ is the ballistics parameter. Solution of Eq. 2*a* for y, and substitution of this expression for y into Eq. 1*a* then yields the following equation for w and its derivatives:

$$\frac{q_0}{2}\left[1 - \frac{w\dot{w}}{(\dot{w})^2}\right] = 1 + A\left[\frac{w^5}{-\dot{w}}\right]^{\frac{1}{4}} \tag{6}$$

where the dots represent differentiation with respect to θ. Now let

$$f(w) = -\dot{w}(\theta) > 0. \tag{7}$$

Then Eq. 6 can be written

$$\frac{q_0}{2}\left[1 - \frac{wf'}{f}\right] = 1 + A\left(\frac{w^5}{f}\right)^{\frac{1}{4}} \tag{6a}$$

where the primes denote differentiation with respect to w. If

$$f = w^{1-2/q_0}\phi(w) \tag{8}$$

then Eq. 6*a* becomes

$$\frac{-q_0}{2}\frac{\phi'}{\phi} = Aw^{1/2q_0}\phi^{-\frac{1}{4}}. \tag{9}$$

Subsequent substitution of

$$p(w) = \phi^{\frac{1}{4}} \tag{10}$$

for ϕ in Eq. 9 then leads to the equation

$$-2q_0p' = Aw^{1/2q_0} \tag{11}$$

for which the solution is readily obtained as

$$p = \left[\frac{AW}{1 + 2q_0} + 1\right]W^{1/2q_0} - \frac{Aw^{1+1/2q_0}}{1 + 2q_0}$$

$$= B - \frac{A}{1 + 2q_0}w^{1+1/2q_0} \tag{12}$$

where the constant of integration is obtained by substituting the initial conditions for w and y into Eqs. 2*a*, 7, 8, and 10.

Hence, from Eqs. 2*a*, 7, 8, 10, and 12,

$$f = -\frac{dw}{d\theta} = \left[\frac{A}{1+2q_0}\right]^4\left[\left(W + \frac{1+2q_0}{A}\right)W^{1/2q_0} - w^{1+1/2q_0}\right]^4 w^{1-2/q_0}$$

$$= \left[\frac{A}{1+2q_0}\right]^4\left[C - w^{1+1/2q_0}\right]^4 w^{1-2/q_0}, \tag{13}$$

and, from Eqs. 2*a* and 4,

$$(D/D_0)^2 = y^4 = \left[\frac{1+2q_0}{A}\right]^4 \frac{w^{2/q_0}}{\left[C - w^{1+1/2q_0}\right]^4}. \tag{14}$$

Equation 14 thus gives a direct relation between the diameter and velocity, in terms of the still-air evaporation rate and the initial Reynolds number of the droplets, and reduces to Eq. 11 of Reference (6) for $A = 0$.

The variation of w with θ can be determined by direct integration of Eq. 13. To facilitate this integration let

$$\left.\begin{aligned} z &= w^{1+1/2q_0} \\ Z &= W^{1+1/2q_0} \\ dz &= \left(1 + \frac{1}{2q_0}\right)w^{1/2q_0}dw \end{aligned}\right\} \tag{15}$$

Then

$$\theta = 2q_0\frac{(1+2q_0)^3}{A^4}\int_z^Z \frac{z^{\frac{3-2q_0}{1+2q_0}}dz}{\left[C - z\right]^4}. \tag{16}$$

Similarly, from Eqs. 3, 5, 13 and 15

$$x = \int_0^t V dt = \frac{2D_0^2|U_0 - V_0|}{k}\int_0^\theta (1 - w^2)d\theta$$

$$= \frac{2D_0^2|U_0 - V_0|}{k}\int_w^W \frac{(1-w^2)dw}{f}$$

$$= \frac{4q_0|U_0 - V_0|D_0(1+2q_0)^3}{A^4 k}\int_z^Z \frac{(1 - z^{\frac{4q_0}{1+2q_0}})z^{\frac{3-2q_0}{1+2q_0}}dz}{\left[C - z\right]^4}. \tag{17}$$

Inspection of Eqs. 16 and 17 reveals that there are only a few discrete values of q_0 for which the integrals can be expressed in closed form. Since the integral of Eq. 17 consists of the sum of two terms, one of which is the integral of Eq. 16, it is apparent that any value of q_0 which permits a closed form solution of Eq. 17 will also lead to an integral in closed form for Eq. 16. To date, the only values of q_0 for which Eq. 17 can be integrated are $\frac{1}{6}$, $\frac{1}{2}$, and $\frac{3}{2}$. The corresponding expressions for θ and x are listed in Table I.

TABLE I.—*Droplet Ballistics Equations for Discrete Values of the Parameter, q_0.*

q_0	Distance, $\left(\frac{A}{1+2q_0}\right)^3 \frac{Akx}{\lvert U_0 - V_0\rvert D^2}$	Time, $\left(\frac{A}{1+2q_0}\right)^3 \frac{Akt}{D^2}$
$\frac{1}{6}$	$\frac{1}{36}\left[\frac{8C^2(1-\sqrt{z})}{(C-z)^3} - \frac{2C(12-13\sqrt{z})}{(C-z)^2} + \frac{3(8-11\sqrt{z})}{(C-z)} + \frac{15}{2\sqrt{C}}\log_e\left\lvert\frac{\sqrt{C}+\sqrt{z}}{\sqrt{C}-\sqrt{z}}\right\rvert\right]_z^z$	$\frac{1}{9}\left[\frac{C^2}{(C-z)^3} - \frac{3C}{(C-z)^2} + \frac{3}{(C-z)}\right]_z^z$
$\frac{1}{2}$	$2\left[\frac{C-C^2}{3(C-z)^3} - \frac{1-2C}{2(C-z)^2} - \frac{1}{C-z}\right]_z^z$	$\frac{1}{3}\left[\frac{2C}{(C-z)^3} - \frac{3}{(C-z)^2}\right]_z^z$
$\frac{3}{2}$	$\frac{1}{4}\left[\frac{8(1-C\sqrt{z})}{(C-z)^3} + \frac{14\sqrt{z}}{(C-z)^2} - \frac{3\sqrt{z}}{C(C-z)} - \frac{3}{2C\sqrt{C}}\log_e\left\lvert\frac{\sqrt{C}+\sqrt{z}}{\sqrt{C}-\sqrt{z}}\right\rvert\right]_z^z$	$2\left[\frac{1}{(C-z)^3}\right]_z^z$

The variations of $V/U_0 = 1 - w^2$ with x/L for $V_0 = 0$, $q_0 = \frac{1}{6}$, $\frac{1}{2}$, and $\frac{3}{2}$, and $A = 1$, 3, and 10, are shown in Fig. 1, where L is the total

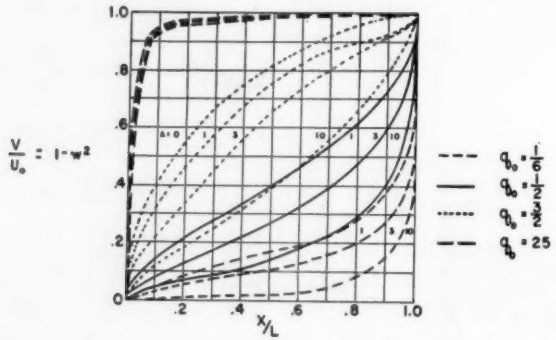

FIG. 1. Theoretical variation of droplet velocity with distance for various values of the parameters.

distance of droplet travel before complete evaporation, as determined from Eq. 17. From this figure, it is apparent that a decrease in q_0 or an increase in A, each of which represents an increase in evaporation rate, leads to a decrease in the droplet's velocity for a given displacement. For $q_0 < 2$, the velocity curve for a droplet with no initial velocity will have vertical tangents for $x/L = 0$ and 1, as can be deduced from Eq. 17. For comparison purposes, the curve for $A = 0$ (constant evaporation rate) and $q_0 = \frac{3}{2}$ is plotted from Eqs. 11 and 12 of Ref. (6). It is noted that this curve lies above the other curves for the same value of q_0, and that the assumption of a constant evaporation rate leads to a horizontal tangent for $x/L = 1$.

Figure 2 shows the theoretical variation of $(D/D_0)^2 = y^4$ with θ/Θ for various values of q_0 and A, where Θ is the value of θ for $y = 0$. From

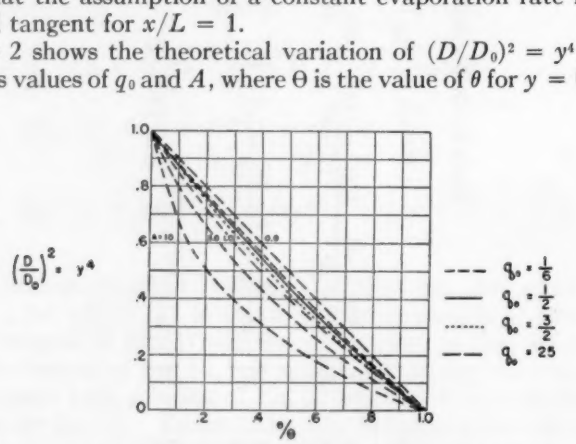

FIG. 2. Theoretical variation of droplet diameter with time for various values of the parameters.

this figure it is apparent that an increase in either q_0 or A brings about a more rapid relative decrease in droplet size, as predicted by Eqs. 14 and 16.

The variation of $L\lambda_0/U_0D_0^2$ with q_0 for $V_0 = 0$, and $A = 0$, 1, 3, and 10 is shown in Fig. 3. The curve for $A = 0$, as determined by Eq. 13 of Ref. (6), thus represents the upper limit on the total distance

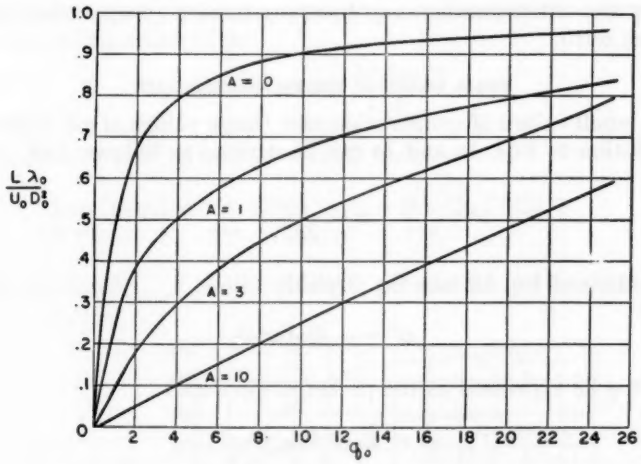

FIG. 3. Theoretical variation to total distance of travel with q_0 for various values of the parameter A.

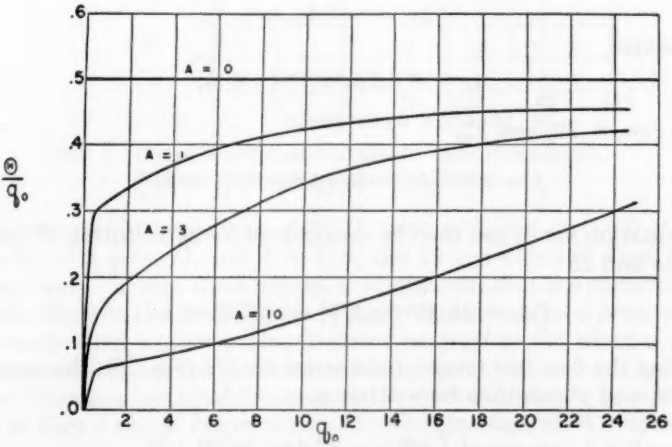

FIG. 4. Theoretical variation of droplet lifetime with q_0 for various values of the parameter A.

travelled during the droplet lifetime, as could be expected from Eq. 1*a*. An increase in A results in a decrease in the distance of travel, as could be expected. All curves approach a value of unity as q_0 becomes infinite.

The corresponding variation of $\Theta/q_0 = T\lambda_0/2D_0^2$ with q_0, where T is the lifetime of the droplet, is given in Fig. 4. The horizontal line at $\Theta/q_0 = 0.5$ represents the upper limit, and is approached asymptotically by the other curves as q_0 becomes infinite (evaporation rate approaches zero).

SMALL VALUES OF THE EVAPORATION RATE

For small values of evaporation rate (large values of q_0), a perturbation solution to Eqs. 1*a* and 2*a* can be derived as follows: Let

$$b = \frac{1}{2q_0}. \tag{18}$$

Substitution of Eq. 18 into Eq. 9 yields

$$\phi' = -4bAw^b\phi^{\frac{1}{2}}. \tag{19}$$

Now let ϕ be expressed as the perturbation series

$$\phi = \phi_0 + b\phi_1 + \cdots. \tag{20}$$

Substitution of Eq. 20 into Eq. 19 reveals that ϕ_0 is a constant, and the first-order equation for ϕ_1 becomes

$$\phi_1' = -4A\phi_0^{\frac{1}{2}}w^b, \tag{21}$$

from which

$$\phi_1 = -4A\phi_0^{\frac{1}{2}}w^{1+b}/(1+b). \tag{22}$$

From Eqs. 8, 20, and 22,

$$f = w^{1-4b}[\phi_0 - 4bA\phi_0^{\frac{1}{2}}w^{1+b}/(1+b)]. \tag{23}$$

The equation for ϕ_0 can then be determined by substituting W for w in Eqs. 2*a* and 23:

$$[\phi_0 - 4baW^{1+b}\phi_0^{\frac{1}{2}}/(1+b)]W^{1-4b} = 1. \tag{24}$$

By using the first two terms of the series for $1/f$ (Eq. 23), the equations for θ, x, and y^4 can then be written as

$$\theta \approx \frac{1}{\phi_0}\left[\frac{w^{4b}}{4b} + \frac{4bA\phi_0^{-\frac{1}{2}}w^{1+5b}}{(1+b)(1+5b)}\right]_w^W \tag{25}$$

$$x = \frac{2D_0^2U_0}{k\phi_0}\left[\frac{w^{4b}}{4b} - \frac{w^{2+4b}}{2+4b} + \frac{4bA\phi_0^{-\frac{1}{2}}}{1+b}\left(\frac{w^{1+5b}}{1+5b} - \frac{w^{3+5b}}{3+5b}\right)\right]_w^W \tag{26}$$

$$y^4 = \frac{w^{4b}}{\phi_0}\left[1 + \frac{4bA\phi_0^{-\frac{1}{2}}w^{1+b}}{1+b}\right], \tag{27}$$

respectively. It is noted that the approximation employed in deriving Eq. 25 requires that the same approximation be used in determining the corresponding value of ϕ_0:

$$\phi_0 W^{1-4b} \approx 1 + \frac{4bA\phi_0^{-\frac{1}{2}}}{1+b}. \tag{24a}$$

Consideration of Eqs. 24 and 25 reveals that

$$\lim_{q_0\to\infty}(\Theta/q_0) = \lim_{b\to 0}(2b\Theta) = \tfrac{1}{2} = \lim_{A\to 0}(\lambda_0 T/2D_0^2) \tag{28}$$

as noted previously. A similar limiting process can be applied to Eq. 26.

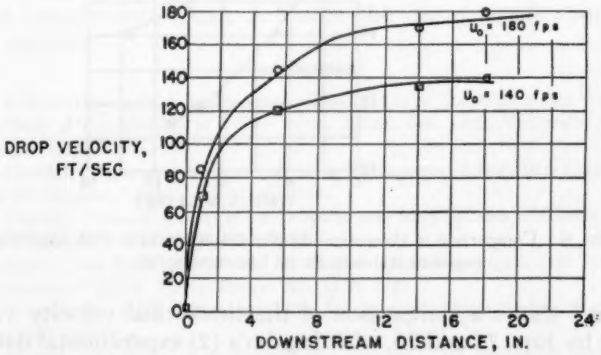

FIG. 5. Comparison of theoretical velocity curve with Ingebo's experimental data for an isooctane spray.

The theoretical variations of V/U_0 with x/L and of $(D/D_0)^2$ with θ/Θ for $V_0 = 0$, $q_0 = 25$, and $A = 1$, 3, and 10, are shown in Figs. 1 and 2, respectively. From these figures, it is apparent that the parameter A has little effect on the shape of the velocity curve, but has a pronounced effect on the drop-size variation, in direct contrast to the effect of A on the corresponding curves for lower values of q_0.

The dimensionless total distance and droplet lifetime for $q_0 = 25$ are shown in Figs 3 and 4, respectively. From these figures, it is apparent that the variation of these quantities with the parameter A follows the same trend as observed for lower values of q_0, but the dissimilar shape of

the curves for $A = 10$ indicates that the first order perturbation solution is inadequate for these values of the parameters. This might well be expected since, for $A = 10$ and $b = 0.02$, the term $4bA$ in Eq. 19 has an appreciable value of 0.8, which invalidates the use of the first-order perturbation solution. Similarly, the appearance of this same relatively large coefficient in Eq. 23 makes the two-term series expansion for $1/f$ highly inaccurate. Further modification of this approximation method by inclusion of additional terms of the series, however, is felt to be unwarranted in view of the limiting assumptions upon which the analysis is based.

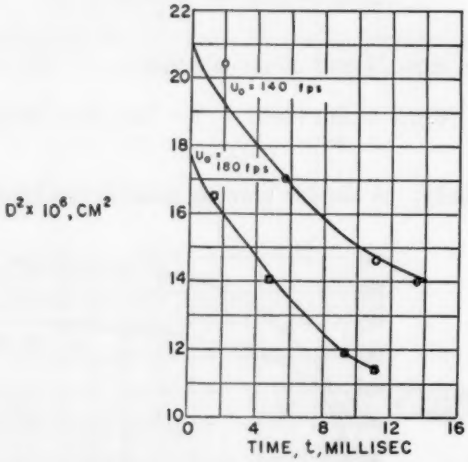

FIG. 6. Comparison of theoretical droplet diameter curve with Ingebo's experimental data for an isooctane spray.

Figure 5 shows a comparison of the theoretical velocity variation, predicted by Eqs. 25 and 26, with Ingebo's (2) experimental data for an isooctane spray injected into air streams of velocity 140 fps. and 180 fps. Since Fig. 1 indicated a small effect of variation in A on the shape of the curve, the same value of $A = 3.4$ was used for both curves. Other parameter values were $b = 0.02$, $\phi_0 = 1.25$, and $k = 0.00567$ cm^2/sec. From the close fit of theoretical curves to the experimental points, it is apparent that the theoretical analysis presented above is applicable to the available experimental data. It is noted the method of presentation of experimental data in Ingebo's second report (3) did not permit comparison with the variations predicted theoretically.

A comparison of the theoretical drop size variation, as determined from Eqs. 25 and 27, with Ingebo's experimental data is shown in Fig. 6. Here again, the closeness of fit is noted, thus providing additional confirmation of the applicability of the present analysis. It is pointed out

that, although Ingebo's velocity data could be fitted by any of several theories (8), the present analysis is the only one to provide a theoretical equation which describes the drop-size variation to within the limits of experimental accuracy.

CONCLUSIONS

As a result of this analysis, the following conclusions can be drawn:

1. The ballistics of a liquid droplet injected into a uniform air stream can be determined analytically for several values of the ballistics parameter, by simultaneous solution of the evaporation and ballistics equations.

2. The effect of the increase in evaporation rate due to relative velocity is similar to the effect of a lower value of q_0, that is, the droplet velocity curve shifts in the direction of the injection velocity, and both the distance traveled and droplet lifetime are reduced.

3. Relative velocity effects produce negligible change in the shape of the velocity curves for low evaporation rates, but cause considerable change in the drop-size curves.

4. Comparison of theoretical velocity and drop-size curves with Ingebo's experimental data indicates the direct applicability of the present analysis.

REFERENCES

(1) R. G. FLEDDERMAN AND A. R. HANSON, "The Effects of Turbulence and Wind Speed on the Rate of Evaporation of a Fuel Spray," Eng. Res. Inst., University of Michigan, Report No. CM667, 1951.

(2) R. D. INGEBO, "Vaporization Rates and Drag Coefficients for Isooctane Sprays in Turbulent Air Streams," NACA TN 3265, 1954.

(3) R. D. INGEBO, "Drag Coefficients for Droplets and Solid Spheres in Clouds Accelerating in Air Streams," NACA TN 3762, 1956.

(4) I. LANGMUIR AND K. B. BLODGETT, "A Mathematical Investigation of Water Droplet Trajectories," USAF Techn. Report No. 5418, 1946.

(5) R. R. HUGHES AND E. R. GILLILAND, "The Mechanics of Drops," *Chem. Eng. Prog.*, Vol. 48, p. 497 (1952).

(6) C. C. MIESSE, "Ballistics of an Evaporating Droplet," *Jet Propulsion*, Vol. 24, p. 237 (1954).

(7) N. FRÖSSLING, "The Evaporation of Falling Drops," *Gerlands Beitrage zur Geophysik*, Vol. 52, p. 170 (1938).

(8) C. C. MIESSE, "Application of Droplet Ballistics Theory to Experiments of Ingebo," *Jet Propulsion*, Vol. 25, p. 35 (1955).

Bonding Plastics to Rubber and Metals.—The world's most widely-used plastic can now, for the first time, be satisfactorily joined directly to rubber, brass or brass-plated metals. Bell Telephone Laboratories has reported that an adhesive many times stronger than any currently used for this purpose makes it possible to achieve a lasting bond between polyethylene and brass or natural and some synthetic rubbers.

Polyethylene, the amazing versatile plastic, has found a place in every American home since its discovery in the 'thirties. It is used to make squeeze bottles for cosmetics, baby bottles, pliable hose and utensils ranging from sieves to dust pans. It is wrapped in thin sheets around fresh fruits and vegetables and other products displayed in stores. One of its principal industrial applications is its use as a covering for telephone cables.

For many years industry has needed a strong adhesive to use with polyethylene. Research at Bell Laboratories has resulted in a simple bonding process that fills this need.

The application of a polybutadiene product as an adhesive and the physical processes necessary to make this possible are the work of Henry Peters of Bell Laboratories' chemical research department.

The new bonding process developed at Bell Telephone Laboratories makes use of partly hydrogenated polybutadiene, known commercially as Hydropol, which is manufactured by the Phillips Petroleum Co. of Bartlesville, Okla. Any degree of unsaturation of the polybutadiene between three per cent and thirty per cent gives the best bonds. Various materials are added to the Hydropol to make it capable of vulcanization.

By using the Hydropol mixture as a bonding agent excellent bonds can be made between polyethylene and brass or brass-plated metals, and between polyethylene and neoprene, natural rubber, or GR-S synthetic rubber. Apparently the hydrogenated polybutadiene adheres to the polyethylene because of its similar chemical structure and thermoplastic properties. The bond to a vulcanizable rubber is probably due to the formation of sulphur crosslinks at the interface that occur during the vulcanizing process.

A layer of bonding agent two to three mils thick is desirable for proper adhesion. The agent may be made up in a solution and sprayed, brushed, or dipped to provide the desired layer, or a thin sheet can be fabricated and inserted between the materials to be bonded.

Peel strengths up to 100 psi. and tensile strengths of 1000 psi. can be readily achieved. These values are considerably higher than have been possible with previously available techniques.

The bonding agent will be of considerable value to the Bell Telephone System and to the plastics and rubber industries. Some of its major applications may be: the bonding of insulation to conductors in plastic "drop wire" used to extend telephone service from the line to the home, and in the bonding of polyethylene to brass in submarine cable repeaters (amplifiers) for underwater telephone cables.

Other significant uses will be the bonding of linings to tanks and the bonding of polyethylene coatings on plating racks or wherever else they are needed.

The process will protect metals from corrosion since the polyethylene can be fixed directly upon the metal without the use of intermediate material other than the adhesive.

The need for such an adhesive has been particularly acute in such communication equipment as undersea telephone cables.

ON THE PHYSICAL INTERPRETATION OF THE RELATIVISTIC CORRECTIONS TO THE VAN DER WAALS FORCE FOUND BY PENFIELD AND ZATSKIS

BY

E. A. POWER [1] AND S. ZIENAU [1]

ABSTRACT

A detailed discussion of the relativistic corrections to the Van der Waals force is given for a simple model in which the neutral atoms are replaced by two linear oscillators orientated along the line of centers. The repulsive corrections proportional to $1/R^6$ and $1/R^7$ found by Penfield and Zatskis (8)[2] are considered in conjunction with the complete corrections obtained by Casimir and Polder (4) in a realistic model.

It is shown that in the limit of electrodynamic interest, that is, separations large compared with the wavelength corresponding to the harmonic oscillator frequency, the total force is attractive and proportional to $1/R^8$: the Penfield and Zatskis correction, valid at near distances only, is dominated by the static London $1/R^7$ attraction.

I. INTRODUCTION

In a recent issue, R. H. Penfield and H. Zatskis (8) have obtained corrections to the Van der Waals force between two neutral atoms by considering relativistic corrections to a linear harmonic oscillator model for the atom. It is not clear from their work what is the connection between these corrections to the interatomic potential and the detailed fourth order calculation of Casimir and Polder (4) and to recent experimental work of Derjaguin *et al* (5), who measure the force in the region $R > \lambda\!\!\!^{-}$, where R is the separation between the atoms and λ the wavelength of the light emitted in the radiative transition from the excited state by the neutral atom; $\lambda\!\!\!^{-} = \dfrac{\hbar c}{E}$ where $E = \hbar\omega_0$ is the energy of the oscillator in Penfield and Zatskis' model. In this note we show that the main correction term in the potential energy of Penfield and Zatskis is contained in the result of Casimir and Polder and is irrelevant in the region of interest $R > \lambda\!\!\!^{-}$ where the London–Van der Waals energy becomes proportional to R^{-7}. In the region $R < \lambda\!\!\!^{-}$, to which as we show the considerations of Penfield and Zatskis are limited, this correction is dominated by the remaining static interaction energy of London $\propto R^{-6}$. The further correction terms, proportional to R^{-6} and higher powers of R^{-1} are mixed polarization and radiative correction terms, the expansion parameter being $\left(\dfrac{\hbar c}{E}\dfrac{\hbar}{mc}\right)^{\frac{1}{2}}\dfrac{1}{R}$. Actually the largest correction of

[1] Departments of Mathematics and Physics, respectively, University College, London, England.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

this type, due to overlap of the atoms, is ignored in Penfield and Zatskis' calculation.

II. THE APPROXIMATE LAGRANGIAN AND HAMILTONIAN OF PENFIELD AND ZATSKIS

The method of calculation used by Penfield and Zatskis is the one which for the case of point charges in motion leads to the Darwin Lagrangian (cf. Landau and Lifshitz (**7**)) and it is well known that the region of validity for this expansion is $R < \lambda\!\!\!^{-}$; the electrodynamic potentials have been expanded in powers of the retardation $R < tc$ where t, the time of transmission of the light between the atoms, is in turn dominated by $\hbar/E$, the period of atomic motion, in order that the sources do not change significantly during the time of transmission. Thus straightforward corrections to the London–Van der Waals energy arising from the radiative interaction in the Darwin limit where it is dominated by the magnetic forces must be of type

$$\frac{\hbar c\alpha(1)\alpha(2)}{\lambda\!\!\!^{-}R^6} \sum_{n=1} a_n(R/\lambda\!\!\!^{-})^n$$

where $\alpha(1)$, $\alpha(2)$ are the (static) polarizabilities of the neutral atom; in the linear harmonic oscillator model these are given by $e^2\hbar^2/(E^2m)$, so that the corrections are

$$\frac{e^4\hbar^4}{R^6E^2m^2} \sum_{n=1} a_n \left(\frac{RE}{\hbar c}\right)^n.$$

It turns out that the first non-vanishing coefficients in the series occur for $n = 2: a_2 = \frac{1}{2}$ (cf. below) so that

$$\frac{1}{2}\frac{\hbar^2e^4}{Em^2c^2}\frac{1}{R^4}$$

is the first "radiative" repulsive correction to the Van der Waals energy in the region $R < \lambda\!\!\!^{-}$. There are correction terms of higher n, that is, *lower* powers of $(1/R)$. That these are unobtainable from the Hamiltonian of Penfield and Zatskis is not hard to see. The main difficulty to remedy this is recognition of the precise region of validity of a Hamiltonian function deduced from an approximative Lagrangian. In fact the Darwin Lagrangian gives rise to the Breit Hamiltonian (**2**, **7**) only under a further approximation, namely, expansion in powers of $(e^2/\hbar c)$, since the canonical momentum differs from the kinetic momentum by such terms. This is best seen by carrying through the deduction of this Hamiltonian from the standard formalism of quantum electrodynamics: here one first does perturbation theory to order $e^2/\hbar c$ on the (transverse) photon interaction and then introduces the further assumption $R < \lambda\!\!\!^{-}$ which implies $\hbar\omega_0 <$ (energy of exchanged transverse quantum). It

would not, however, be consistent to use this Hamiltonian to carry through a perturbation expansion in powers of $e^2/\hbar c$ since terms of order $(e^2/\hbar c)^2$ have been negelected in the derivation of the Hamiltonian. Thus the correction terms found with use of a Breit type Hamiltonian in the problem under discussion can only be part of the total correction valid to order $e^4/\hbar^2c^2$: namely, that part of the energy which arises from interference between the Coulomb energy $\frac{2x_1x_2}{R^3}$ and the Breit-like interaction $\frac{2v_1v_2}{R}$ acting at separate times. Here we are using the language of Feynman in the context of stationary perturbation theory. One may verify this quite simply by considering the four time ordered Feynman graphs of Fig. 1.

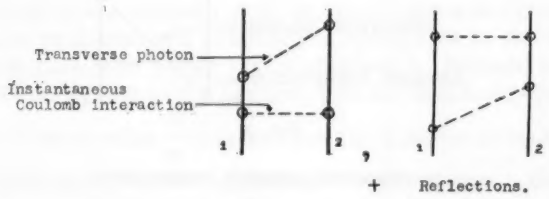

FIG. 1.

The contribution of these four graphs to the energy shift is

$$U = 4\frac{(2\pi)e^4}{m^2}\sum_{\mathbf{k}\lambda}\frac{\langle p_x^{(1)}\rangle\langle p_x^{(2)}\rangle e_x(\mathbf{k}\lambda)e_x(\mathbf{k}\lambda)e^{ik_xR}}{2\omega_0k(\omega_0+k)}\cdot\frac{2\langle q_x^{(1)}\rangle\langle q_x^{(2)}\rangle}{R^3} \qquad \hbar = c = 1$$

where the $e_x(\mathbf{k}\lambda)$ are the x components of the polarization vectors ($\lambda = 1,2$) of the transverse photon, $\langle p_x^{(i)}\rangle$, $\langle q_x^{(i)}\rangle$ are matrix elements of the canonical momentum and mechanical moment of atom respectively and where we have specialized to the case of two parallel moments, parallel to the line of separation (x-axis). In the limit $\omega_0 \ll k$, U reduces to

$$\frac{1}{2}\frac{\hbar e^4}{m^2\omega_0c^2}\frac{1}{R^4}.$$

However use of Breit's formalism will ignore many important terms, for example, those of order $1/R^3$ which arise from interference of a transverse photon and the Coulomb interaction while the former is actually being exchanged, cf. Fig. 2. Such contributions to the energy cannot be computed by simply taking the Breit interaction matrix element with the frequencies modified by the Coulomb energy as can be done for the $1/R^4$ terms and which gives the simple model to compute the London

energy $\propto 1/R^6$ as in Born's book (1). All contributions from terms which involve two photon vertices due (in the normal Hamiltonian) to the interaction $\frac{e^2\mathbf{A}^2}{2mc^2}$, where $\mathbf{A}$ is the transverse vector potential, are even less accessible to this formalism. From a strict relativistic point of view, these contributions arise from transitions via negative energy states of the Dirac electron, or more precisely they involve positron theory. These are essential to obtain the complete interaction between two neutral atoms correct to order $e^4/\hbar^2c^2$.

Dŝjaloshinsky (6) has used the completely covariant version of quantum electrodynamics for this problem and effected the non-relativistic reduction directly in the matrix element for the energy shift.

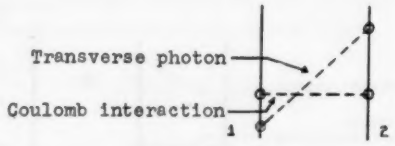

FIG. 2.

III. COMPLETE RADIATIVE CORRECTIONS

All corrections to order $e^4/\hbar^2c^2$ have been evaluated some time ago by Casimir and Polder (4) who found for the case of two parallel dipole atoms, the dipoles being parallel to the line of separation,

$$U = -\frac{8k_0^2e^4\langle q^{(1)}\rangle^2\langle q^{(2)}\rangle^2}{\pi\hbar cR^2}\int_0^\infty \frac{u^4due^{-2uR}}{(k_0^2+u^2)^2}\left(\frac{1}{uR}+\frac{1}{u^2R^2}\right)^2.$$

In this formula $\mathbf{k}_0 = E/\hbar c = \omega_0/c$, and to specialize to the linear oscillator, $\langle q\rangle^2 = \hbar/(2m\omega_0)$. In the limit $R < \lambda$ this gives rise to an expansion in power of $\frac{R\omega_0}{c}$,

$$U = -\frac{\hbar e^4}{2m^2\omega_0^3}\cdot\frac{1}{R^6}+\frac{1}{2}\frac{\hbar e^4}{m^2\omega_0c^3}\frac{1}{R^4}+\cdots$$

whereas in the opposite limit $\lambda < R$ an expansion in powers of $\frac{c}{R\omega_0}$ is easily obtained,

$$U = -\frac{5}{2\pi}\frac{\hbar ce^4}{m^2\omega_0^4}\cdot\frac{1}{R^7}+\cdots.$$

In this latter limit, which is the one where retardation is dominant, the law of force forms the basis for the interpretation of the experiments of Derjaguin *et al* (5) and Prosser and Kitchener (10). The correction

terms to the R^{-7} law are potential energies which fall off like R^{-8} and even faster. The possibility of reducing the Lagrangian in this limit to one containing particle coordinates only and hence obtaining a valid Hamiltonian in closed form is of interest, but this problem seems inaccessible at present. Recently we have succeeded in simplifying considerably the electrodynamic Hamiltonian in non-relativistic and dipole approximation for neutral sources, and obtain Casimir's formula by a fourth order perturbation calculation on a single interaction energy density

$$- \int (\mathbf{P}(\mathbf{x}) \cdot \mathbf{E}^t(\mathbf{x})) d\mathbf{x}$$

where $\mathbf{E}^t(\mathbf{x})$ is the transverse electric field vector and

$$\mathbf{P}(\mathbf{x}) = - e\mathbf{q}^{(1)}\delta(\mathbf{x} - \mathbf{x}_1) - e\mathbf{q}^{(2)}\delta(\mathbf{x} - \mathbf{x}_2)$$

for two neutral atoms situated at $\mathbf{x}_1$, $\mathbf{x}_2$ (cf. Power and Zienau, 9).

It remains to discuss the polarization corrections to the interaction energy and in particular the R^{-6} term obtained by Penfield and Zatskis as a repulsive correction to the London–Van der Waals energy. We see at once that it is of order $\frac{E}{m}$ smaller than the London attractive contribution and thus negligible in comparison. It arises from taking a better approximation to the distance between the moving charges than R, the distance between the heavy centers to which they are attached. However, the leading terms of this type will arise from corrections to the static Coulomb interaction. In the simple linear oscillator model of Penfield and Zatskis, it will give rise to an attractive energy of form $\frac{e^4\hbar^2}{m^3\omega_0^4} \cdot \frac{1}{R^8}$. The actual form depends rather critically on the model and is of course much better computed by considering the exact wave functions in a more realistic atomic model (cf. Buckingham, 3). The term which Penfield and Zatskis compute is the polarization correction to the leading relativistic correction in the limit $\lambda > R$ in the linear harmonic oscillator model.

REFERENCES

(1) M. BORN, "Atomic Physics," sixth edition, London and Glasgow, Blackie, 1957.
(2) G. BREIT, *Phys. Rev.*, Vol. 39, p. 616 (1932).
(3) R. A. BUCKINGHAM, *Proc. Roy. Soc.*, Vol. A 160, p. 94 (1937).
(4) H. B. G. CASIMIR AND D. POLDER, *Phys. Rev.*, Vol. 73, p. 360 (1948).
(5) B. V. DERJAGUIN, I. I. ABRIKOSOVA AND E. M. LIFSHITZ, *Quarterly Reviews*, Vol. 10, p. 295 (1956).
(6) J. E. DŜJALOSHINSKY, *J.E.T.P.* (U.S.S.R.), Vol. 30, p. 1152 (1956).
(7) L. LANDAU AND E. M. LIFSHITZ, "The Classical Theory of Fields," Cambridge, Mass., Addison-Wesley, 1951.
(8) R. H. PENFIELD AND H. ZATSKIS, JOUR. FRANKLIN INST., Vol. 263, p. 331 (1957).
(9) E. A. POWER AND S. ZIENAU, *Nuovo Cimento*, Vol. 6, p 7 (1957).
(10) A. P. PROSSER AND J. A. KITCHENER, *Nature*, Vol. 178, p. 1339 (1956).

Program MOONBEAM for Amateur Tracking of IGY Earth Satellite.—A program for volunteer radio tracking of the scientific earth satellite has been announced by the IGY Committee of the National Academy of Sciences. To be known as MOONBEAM, the program will organize and provide technical assistance to amateur radio groups for the operation of simplified tracking systems during the International Geophysical Year. These systems will enable volunteers to locate the IGY satellite in its flight and to receive scientific data transmitted from it.

The Naval Research Laboratory has been named to head the MOONBEAM project, with the assistance of the Jet Propulsion Laboratory of the California Institute of Technology. The American Radio Relay League will give active support to the program.

The MOONBEAM program will materially assist the primary satellite tracking system, known as Minitrack, which is under the direction of the Naval Research Laboratory. This system uses radio signals transmitted from the satellite both for precision tracking and for the recording of scientific data.

The simplified tracking system which has been developed for use in MOONBEAM is designated Minitrack Mark II. It was designed and constructed by the Naval Research Laboratory and subjected to elaborate testing to demonstrate its suitability for use in radio tracking. In addition, the Jet Propulsion Laboratory has developed a second system, Microlock, capable of receiving the Minitrack signals from the satellite.

The IGY Committee expects that the cost of these systems will be within the reach of interested amateurs. The MOONBEAM stations which they will establish will be able to provide tracking data of sufficient accuracy to be of great value in the scientific experiments which will be conducted in connection with the IGY earth satellite.

Of particular importance will be the role of MOONBEAM volunteers in detecting small deviations in the satellite's orbit due to local irregularities in gravity and in recording scientific data which might be telemetered from the satellite coincident with a solar flare.

MOONBEAM teams may be able to make other important contributions to the IGY program by (1) providing supplemental acquisition data (in initially locating the satellite), (2) providing additional data on the effects of the ionosphere, the electrically charged layers of the upper atmosphere, on radio signals, (3) providing time and position checks for the primary recording of data from certain satellite experiments, (4) providing data upon the occasion of serious damage to the satellite, should this occur.

Requests for technical information and consulting assistance on equipping, establishing, and operating stations in the MOONBEAM volunteer radio network should be directed to the Satellite Office, IGY Committee of the National Academy of Sciences, Washington, D. C.

The American Radio Relay League will also play a key role in the volunteer radio tracking program. Through its magazine, *QST*, design information on the primary amateur systems, Minitrack Mark II and Microlock, is being provided to radio amateurs. In addition, it is planned that technical and operational information concerning the MOONBEAM program will be carried in bulletin sheets in *QST*.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

October 16, 1957

The Stated Meeting of The Franklin Institute was held at 8:15 P.M. in Franklin Hall, following the Annual Medal Day Reception and Dinner, at which 362 members and guests were present.

Dr. S. Wyman Rolph, President, called the meeting to order and announced that the minutes of the May Stated Meeting had been printed in the June issue of the JOURNAL OF THE FRANKLIN INSTITUTE. There being no corrections or additions, the minutes were approved as published.

President Rolph introduced the Executive Vice President of The Institute, Dr. John S. Burlew, who gave an interesting report on the "Coming Events at The Franklin Institute."

President Rolph spoke of the work of men of science that is being conducted on a world-wide basis and the efforts of these men to gain a greater understanding of the universe in which we live. In paying tribute to the men to be honored, Dr. Rolph appropriately quoted Dr. Franklin, "God grant that not only the love of liberty but the thorough knowledge of the rights of man may pervade all the nations of the earth, so that a philosopher may set his foot anywhere in the earth's surface and say—'This is my country'."

The Sponsors then presented their candidates for this year's awards, and the presentation of the Medals was made by President Rolph. Following the presentation of these awards, Dr. Hugh Stott Taylor, recipient of the Franklin Medal, gave a very interesting talk on "Deliberate Speed," a phrase which, Dr. Taylor said, the catalytic chemist may appropriate also to define his activities in the field of chemistry.

The meeting was adjourned at 10:07 P.M.

WILLIAM F. JACKSON, JR.
Secretary

PROGRAM

Reception for Medalists.....THE HOSTESS COMMITTEE

Invocation.....THE VERY REVEREND J. JOSEPH BLUETT, S.J.

Dinner.....MEDALISTS, OFFICIALS AND GUESTS

Toast to Benjamin Franklin.....S. WYMAN ROLPH, *President*

Introduction of Former Medalists.....
.....JOHN H. NEHER, *Chairman, Committee on Science and the Arts*

Stated Meeting of the Institute.....THE PRESIDENT PRESIDING

Coming Events at the Institute.....JOHN S. BURLEW, *Executive Vice President*

Presentation of Medalists.....COMMITTEE ON SCIENCE AND THE ARTS

Award of Medals.....THE PRESIDENT

"Deliberate Speed".....HUGH STOTT TAYLOR

MEDALISTS

To be Awarded Cresson Medals (1848)

WILLARD FRANK LIBBY

Commissioner
U. S. Atomic Energy Commission
Washington, D. C.

REGINALD JAMES SEYMOUR PIGOTT

Consulting Engineer
Pittsburgh, Pennsylvania

ROBERT A. WATSON-WATT

Radiophysicist
Thornhill, Ontario, Canada

To be Awarded a Longstreth Medal (1890)

JOHN BERTRAND JOHNSON

Head, Physics Department
Edison Laboratory
Thomas A. Edison Industries
McGraw-Edison Company
West Orange, New Jersey

To be Awarded a Levy Medal (1923)

DAVID BARNARD STEINMAN

Consulting Engineer
New York, New York

To be Awarded a Henderson Medal (1924)

ASSOCIATION OF AMERICAN RAILROADS

Received by
WILLIAM T. FARICY, *President*

To be Awarded Wetherill Medals (1925)

WARREN W. CARPENTER

Research Consultant
Winter Park, Florida

THE MARTIN COMPANY

Received by
G. T. WILLEY, Vice President Manufacturing

To be Awarded a Brown Medal (1938)

PIER LUIGI NERVI

Architect-Engineer
Rome, Italy

To be Awarded a Clamer Medal (1943)

WILLIAM G. PFANN

Metallurgist
Bell Telephone Laboratories
Murray Hill, New Jersey

To be Awarded Ballantine Medals (1946)

ROBERT MORRIS PAGE

Associate Director of Research for Electronics
U. S. Naval Research Laboratory
Washington, D. C.

LEO CLIFFORD YOUNG

Electronics Consultant
U. S. Naval Research Laboratory
Washington, D. C.

To be Awarded The Franklin Medal (1914)

HUGH STOTT TAYLOR

Dean of the Graduate School and the
David B. Jones Professor of Chemistry
Princeton University
Princeton, New Jersey

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 420 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays.

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AIR POLLUTION

MEETHAM, A. R. Atmospheric Pollution. Ed. 2. 1956.

ASTRONOMY

BEYNON, W. J. G. AND BROWN, G. M., ED. Solar Eclipses and the Ionosphere. 1955.
DUFAY, JEAN. Galactic Nebulae and Interstellar Matter. 1957.
VAUCOULEURS, GÉRARD HENRI DE. Discovery of the Universe. 1957.

BIOLOGICAL CHEMISTRY

BRAY, H. GEOFFREY AND WHITE, KENNETH. Kinetics and Thermodynamics in Biochemistry. 1957.

CHEMISTRY AND CHEMICAL TECHNOLOGY

CARTMELL, B. AND FOWLES, G. W. A. Valency and Molecular Structure. 1956.
MOELWYN-HUGHES, E. A. Physical Chemistry. 1957.
MORRISON, GEORGE H. AND FREISER, HENRY. Solvent Extraction in Analytic Chemistry. 1957.
MULDOON, HUGH C. AND BLAKE, MORTIN E. Systematic Organic Chemistry. 1957.
NEBERGALL, WILLIAM H. AND SCHMIDT, FREDERIC C. College Chemistry. 1957.
SIENKO, MICHELL J. AND PLANE, ROBERT A. Chemistry. 1957.

CRYSTALLOGRAPHY

PORTER, M. W. AND SPILLER, R. C. Barker Index of Crystals. Vol. 2. 1956.

ECONOMICS

ALLEN, R. G. D. Mathematical Economics. 1956.
KLEIN, LAWRENCE R. Econometrics. 1956.

ELECTRICITY AND ELECTRICAL ENGINEERING

CROWHURST, NORMAN H. Understanding Hi-Fi Circuits. 1957.
MCPORTLAND, JOSEPH F. Electrical Systems Design. 1956.
WILLIAMS, EVERARD M. AND WOODFORD, JAMES B. Transmission Circuits. 1957.

ENGINEERING

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HUNTINGTON, WHITNEY CLARK. Earth Pressures and Retaining Walls. 1957.
PARKER, EARL RANDALL. Brittle Behavior of Engineering Structures. 1957.

GEOLOGY

DUNBAR, CARL OWEN AND RODGERS, JOHN. Principles of Stratigraphy. 1957.

HOROLOGY

GEISSLER, J. G., ED. Der Uhrmacher oder Lehrbegrit der Uhrmacherkunst. 10 vol. 1793–1799.
HUMBERT, BERNARD. Swiss Self-Winding Watches. 1956.

MATHEMATICS

BRIOT, JEAN CLAUDE AND BOUQUET, CHARLES AUGUSTE ALBERT. Théorie des Fonctions Elliptiques. Ed. 2. 1875.
FLAMMER, CARSON. Spheroidal Wave Functions. 1957.
FRICKE, ROBERT AND KLEIN, FELIX. Automorphen Functionen. 2 Vols. 1897–1912.
WEISSENBORN, HERMANN. Die Cyclischen Curven. 1856.
WELLMAN, B. LEIGHTON. Technical Descriptive Geometry. Ed. 2. 1957.

MECHANICAL ENGINEERING

BEVAN, THOMAS. The Theory of Machines. Ed. 3. 1956.
PHELAN, RICHARD M. Fundamentals of Machine Design. 1957.

METALLURGY

QUENEAU, BERNARD RUSSELL. The Embrittlement of Metals. 1956.

METEOROLOGY

LOGWINOW, K. T. Dynamische Meteorologie. 1955.

NUCLEAR ENGINEERING

HUGHES, D. J.; MCLAIN, STUART AND WILLIAMS, CLARD, ED. Selected Papers from the 1st Nuclear Engineering and Science Congress. 1957.
JOINT ESTABLISHMENT FOR NUCLEAR ENERGY RESEARCH (NETHERLANDS AND NORWAY). Proceedings of the Kjeller Conference on Heavy Water Reactors. 1953.

OPTICS

HALL, CECIL E. Introduction to Electron Microscopy. 1953.
JENKINS, FRANCIS ARTHUR AND WHITE, HARVEY E. Fundamentals of Optics. Ed. 3. 1957.
SJÖSTRAND, F. S. AND RHODIN, J., ED. Electron Microscopy. Proceedings of the Stockholm Conference. 1957.

PETROLEUM TECHNOLOGY

HAVE, J. H. VAN DER AND VERVER, C. G. Petroleum and its Products. 1957.

PHOTOGRAPHY

COLLINS, R. B., ED. Proceedings of the Third International Congress in High-Speed Photography. 1957.

PHYSICS

BORN, MAX. Physics in my Generation. 1956.
GINZTON, EDWARD L. Microwave Measurements. 1957.
HUNTER, JOSEPH L. Acoustics. 1957.
KRAMERS, HENDRIK ANTHONY. The Foundations of Quantum Theory. 1957.
PRZIBRAM, KARL. Irradiation Colours and Luminescence. 1956.
ROSE, MORRIS EDGAR. Elementary Theory of Angular Momentum. 1957.
SYNGE, JOHN LIGHTON. The Relativistic Gas. 1957.
TANG, WALTER K. Properties of Gaseous and Liquid Mixtures. 1956.
WEBER, ROBERT L. AND OTHERS. Physics for Science and Engineering. 1957.
WEIZSÄCKER, C. F. VON AND JUILFS, J. The Rise of Modern Physics. 1957.

SCIENCE

MEIER, RICHARD L. Science and Economic Development. 1956.

TEXTILES

POLANYI, M. Dictionary of Textile Terms. 1956.

MEMBERSHIP

The following elections were approved on October 3, 1957 by the Membership Committee by authority given to it by the Board of Managers.

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TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests —both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Secretary.

AWARDS BY THE INSTITUTE

The Franklin Medal (1914—Gold Medal).—This medal is awarded annually to those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, acting through its Committee on Science and the Arts, have done most to advance a knowledge of physical science or its applications.

The Elliott Cresson Medal (1848—Gold Medal).—This medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfectior in workmanship.

The Howard N. Potts Medal (1906—Gold Medal).—This medal is awarded for distinguished work in science or the arts; important development of previous basic discoveries, inventions or products of superior excellence or utilizing important principles.

The John Price Wetherill Medal (1925—Silver Medal).—This medal is awarded for discovery or invention in the physical sciences or for new and important combinations of principles or methods already known.

The Edward Longstreth Medal (1890—Silver Medal).—This medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes. In the event of an accumulation of the fund for medals beyond the sum of one hundred dollars, it is competent for the Committee on Science and the Arts to offer from such surplus a money premium for some special work on any mechanical or scientific subject that is considered of sufficient importance.

The Louis E. Levy Medal (1923—Gold Medal).—This medal is awarded to the author of a paper of especial merit, published in the JOURNAL OF THE FRANKLIN INSTITUTE, preference being given to one describing the author's experimental and theoretical researches in a subject of fundamental importance.

The George R. Henderson Medal (1924—Gold Medal).—This medal is awarded for meritorious inventions or discoveries in the field of Railway Engineering.

The Walton Clark Medal (1926—Gold Medal).—This medal is awarded to the "author of the most notable advance in knowledge or improvement in apparatus, or in method concerning the science or the art of gas manufacture or distribution or utilization in the production of illumination, or of heat, or of power."

The Frank P. Brown Medal (1938—Silver Medal).—This medal is awarded to inventors for discoveries and inventions involving meritorious improvements in the building and allied industries.

The Newcomen Medal (1943—Gold Medal).—This medal is awarded, not oftener than once in three years, for achievement in the field of Steam.

The Francis J. Clamer Medal (1943—Silver Medal).—This medal is awarded at least once in five years for meritorious achievement in the field of Metallurgy.

The Stuart Ballantine Medal (1946—Gold Medal).—This medal is to be awarded in recognition of outstanding achievement in the fields of Communication and Reconnaissance which employ electromagnetic radiation.

The Boyden Premium (1859).—This premium is awarded not oftener than once in five years to any resident of North America who has recently made a notable experimental determination of the speed, in free space, of radiation in any region of the entire spectrum.

The William M. Vermilye Medal (1937—Bronze Medal).—This medal is awarded not oftener than biennially in recognition of outstanding contribution in the field of Industrial Management.

The Certificate of Merit (1882).—A Certificate of Merit is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices.

For further information relating to these awards apply to the Secretary, Committee on Science and the Arts

THE FRANKLIN INSTITUTE LABORATORIES
FOR RESEARCH AND DEVELOPMENT
NICOL H. SMITH, DIRECTOR

THE MATRIX MATH COMPILER

BY

LAURENCE C. McGINN [1]

Many problems in analysis can be reduced to systems which may be conveniently processed by matrix techniques. Matrix methods allow large quantities of data to be handled in an orderly fashion. Moreover, the algebra of matrices involves much tedious computation and is, therefore, the kind of thing that is particularly amenable to a large scale digital computer.

In the past, matrix problems have been run on UNIVAC. While the routines which handled these problems were individually efficient and versatile, it was nonetheless true that employing a sequence of these routines resulted in confusion and inefficient use of valuable computer time. It was thought that these undesirable features could be eliminated by the creation of a compiler for matrix mathematics.

A matrix math compiler has been under development by the Analysis Section of the Laboratories, under the sponsorship of the Remington Rand UNIVAC Division of the Sperry Rand Corporation. The compiler uses a pseudo-code input in which each pseudo-instruction calls up a subroutine from a library. Most of the library subroutines are modifications of routines initially written by the Computational Division of the U. S. Air Force. As each subroutine is summoned from the library, it is collected with other subroutines onto a magnetic tape which becomes the instruction tape. This process converts very few instructions (pseudo-code) into a large number of instructions (machine code). The finished list of instructions is capable of causing the computer to perform many complex matrix operations and to do so without confusion and loss of time.

Recently, the Matrix Math Compiler was used for a regression analysis problem in mathematical statistics, in which the following were computed for a 20×6 array:

1. The partial regression coefficients,
2. The standard error of the estimate,
3. The significance of the partial regression coefficients,
4. The multiple correlation coefficient, and
5. The correlation coefficients.

[1] Research Engineer, Electrical Engineering Division.

The translation to machine code took five minutes, and the problem solution time was thirty-six minutes. A similar problem without the compiler takes 1.5 hr. on UNIVAC.

The use of the matrix compiler assures a saving of time in matrix problems and its use is limited only by the imagination of those who know matrices.

THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, FOUNDER
WILLIAM G. BATT, DIRECTOR

STRAIN SELECTION OF A HETEROLOGOUS YOLK SAC TUMOR IN SERIAL TRANSPLANTATION TO PREVENT INCREASED CHICK EMBRYO MORTALITY

BY

IRVING GALINSKY AND WILLIAM G. BATT

The serial transfer of mouse mammary tumors in the yolk sac of embryonated eggs has been reported by Heilman and Bittner (1) to be correlated with an increased lethal effect on the chick embryos. An increased chick embryo mortality associated with the increasing number of tumor passages in the egg was also reported by Armstrong and Ham (2) and Taylor and Carmichael (3). Galinsky (4) found that over a period of transplant generations in the egg, a tumor could be obtained which produced a specific deleterious effect on the livers of the chick embryo.

The conclusion seems to be that there is a tendency for a heterologous transplant of tumor in the yolk sac to affect the host embryo more adversely after a number of passages in the eggs. It would appear important to determine whether this was always true or whether it was possible by proper selection to prevent an increase in the lethal effects of a tumor no matter how many generations it had been transferred in the egg.

The present paper is concerned with evidence obtained in the course of 24 serial transplants of a tumor in the egg.

MATERIALS AND METHODS

A Brown-Pearce rabbit carcinoma which has previously been grown only in rabbits was used. The method of yolk sac cultivation was essentially that described by Taylor *et al* (5).

Fertile eggs from a pure strain of White Leghorns were incubated at 99.5° F. The tumor was macerated through stainless steel screens and diluted 1:11 with saline. The yolk sacs of 4-day embryonated eggs were inoculated with 0.4 cc. of the tumor suspension. For continued serial transplantation, the tumors were harvested from eggs that had been incubated for 18 days. The eggs were candled at various intervals after inoculation and embryo mortality was recorded.

The effect of the Brown-Pearce tumor was noted up to 24 transplant generations in the egg. A comparison of the mortality of 11-day embryos and also the number of hatching chicks was made between the various transplant generations.

In order to determine whether the mass of the tumor in the yolk contributed to the mortality, the yolk sacs of a number of non-tumor

eggs were injected with 1.0 cc. of paraffin, which is approximately equal in size to 1.5 gm. of tumor. Two kinds of paraffin were used. One was pure paraffin and the other was the embedding paraffin of Fisher Scientific Company known as Tissuemat. Tissuemat is a mixture of paraffin and some substances designed to make the paraffin less crumbly for sectioning. The paraffin was kept melted by means of a hot plate at 60° C. The needle and syringe were flamed periodically to prevent hardening of the paraffin.

A total of 842 eggs was used for the pure paraffin and 359 eggs for the Tissuemat experiments. There was some variation between the number of eggs from which results were obtained for mortality data at 11 days and at 21 days in the controls and also the tumor eggs. This was because certain of the control eggs were not candled at 11 days while in the tumor eggs some had to be opened at 18 days to harvest tumor for purposes of inoculation. Control data were obtained from 294 eggs at 11 days and 723 eggs at 21 days. Tumor data were obtained from 2,893 eggs at 11 days and 2,172 eggs at 21 days. An over-all total of 4,817 eggs was utilized throughout these experiments.

OBSERVATIONS

The mortality curve (Fig. 1) of 11-day-incubated embryos containing yolk sac tumors from 1 to 24 tumor generations reveals that at one gener-

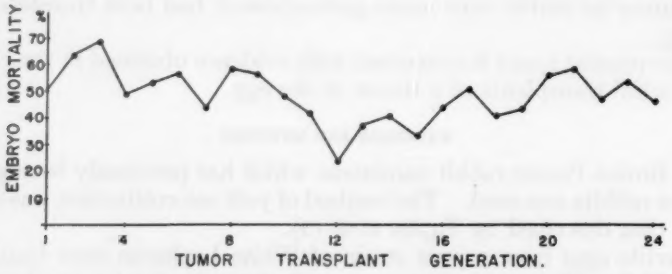

FIG. 1. The trend of chick embryo mortality of serially transplanted tumor through twenty-four tumor generations.

ation there is a 50 per cent mortality and at 24 generations there is still almost a 50 per cent mortality. While the curve is a wavy one, it reveals that there is no distinct trend toward an increase in the lethality of the tumor to the chick embryo. The same type of relationship holds true for the hatchability of chicks from tumor-bearing eggs. There is some fluctuation from batch to batch but no definite decrease that could be associated with an increase in number of tumor generations.

A comparison was made of the mortality of control chicks, chicks with pure paraffin in the yolk sac, those with Tissuemat paraffin in the

yolk sac, and chicks with tumor in the yolk sac. The percentage of chicks dead by 11 days of incubation and also by 21 days of incubation (time of hatching) was the basis of comparison. It can be seen in Table I that pure paraffin causes some increase in mortality while

TABLE I.—*Comparison of Percentage Mortality of Control, Paraffin-injected, and Tumor-injected Eggs.*

Chick Mortality	Control	Paraffin		Tumor
		Pure	Tissuemat	
By 11 days	15.7	33.4	67.4	48.5
By 21 days (hatching time)	59.1	77.5	94.1	91.6

Tissuemat and the Brown-Pearce rabbit tumor produce a much greater increase in lethal effect on the chick embryos. The Tissuemat and the tumor both result in approximately the same number of deaths by the time of hatching but the tumor produces more deaths between the 11th and 21st days of incubation.

DISCUSSION AND CONCLUSIONS

The heterologous Brown-Pearce rabbit tumor has a definite detrimental effect on the host chick embryo as evidenced by the increased mortality over the controls. Since the tumor had no direct contact with the chick embryo, it would appear that the tumor was producing substances which were toxic to the embryo. This conclusion was supported by the similar results obtained with Tissuemat which contained toxic materials not present in pure paraffin. The increased mortality resulting from the pure paraffin was probably due to the temperature at which it was injected.

The degree of toxicity of a heterologous tumor grown in the yolk sac of the chick embryo evidently was not increased with subsequent transplantation of the tumor. The findings in this report would seem to establish that from each generation tumors can be selected that are no more harmful than those of the preceding generation. This can be done by taking tumors from eggs 18 days or older. The tumors in such eggs would of necessity be less injurious to the chick, otherwise the embryo would not have survived this long.

Heilman and Bittner (1) reported that they kept harvesting the tumors earlier and earlier with each subsequent serial passage in eggs. They appeared to have selected a more virulent strain of the tumor as a consequence. Armstrong and Ham (2) and Taylor and Carmichael (3) appeared to have harvested the tumor from eggs incubated about 14 days. At this stage it would be possible to select a strain of tumor deleterious to the chick since many injured chick embryos survive until this time. Since a much smaller proportion of tumor-bearing embryos survive until 18 days of incubation, there would be a greater chance of

selecting a more virulent tumor strain at the early stages of egg incubation than at the later stages. However, Hungate and Snider (6) found no significant increase in the toxicity of a *dba* mouse mammary carcinoma that had been transferred in eggs 32 times. It is interesting to note that the tumor tissue used by them for serial transfer was selected from the longer lived eggs.

A certain number of mutations of either the chromosomal (7) or gene (8) type may be expected to occur during the course of a large number of tumor cell divisions. It is thus possible to have strains of the original tumor that are either more toxic, less toxic or equally as toxic as the original tumor.

At present the evidence would seem to indicate that whether a heterologus tumor became more toxic to the host chick or not depends upon the selection, intentional or unintentional, of a mutant type.

SUMMARY

The increased mortality of chick embryos, associated with the serial cultivation of tumor tissue in the yolk sac, was demonstrated not to be a general phenomenon. From the first generation of growth in the egg, the Brown-Pearce rabbit carcinoma used was selected only from eggs incubated 18 days. This selection resulted in a tumor strain that was not any more lethal to the chick embryo after 24 serial passages in the egg than it was at the first generation.

It was concluded that mutations arise in the tumor cells and strains of tumor can be selected that are more toxic, equally toxic, or less toxic than the original tumor.

The lethal effect of the tumor appears to result from toxic substances produced by the tumor.

REFERENCES

(1) F. R. HEILMAN AND J. J. BITTNER, "Observations on Mouse Tumors Cultivated in the Yolk Sac of the Embryonic Chick," *Cancer Research*, **4**, 578–582 (1944).

(2) M. ARMSTRONG AND A. HAM, "Effects, Particularly Anemia, Produced in Chicks by Growth in Their Yolk Sacs of Mouse Mammary Tumors," *Cancer Research*, **7**, 481–490 (1947).

(3) A. TAYLOR AND N. CARMICHAEL, "The Effect on the Embryo of Continued Serial Tumor Transplantation in the Yolk Sac," *Cancer Research*, **9**, 498–503 (1949).

(4) I. GALINSKY, "Production of Hepatic Abnormalities in Chick Embryos by the Yolk Sac Culture of Mouse Tumor," *Texas Repts. Biol. Med.*, **13**, 62–68 (1955).

(5) A. TAYLOR, N. CARMICHAEL AND T. A. NORRIS, "Further Report on Yolk Sac Cultivation of Tumor Tissue," *Cancer Research*, **8**, 264–269 (1948).

(6) R. E. HUNGATE AND H. SNIDER, "The Nutritional Adequacy of the Embryonated Egg for Growth of a Mammalian Tumor," *Univ. Texas Publ.* No. 4507, "Cancer Studies," 53–63 (1945).

(7) T. C. HSU AND P. S. MOOREHEAD, "Mammalian Chromosomes *in vitro*. VII. Heteroploidy in Human Cell Strains," *J. Natl. Cancer Inst.*, **18**, 463–471 (1957).

(8) EVA KLEIN, "Gradual Transformation of Solid into Ascites Tumors. Evidence Favoring the Mutation-Selection Theory," *Exptl. Cell Research*, **8**, 188–212 (1955).

BOOK REVIEWS

ENGINEERING THERMODYNAMICS, by C. Osborn Mackey, W. N. Barnard and Frank O. Ellenwood. 428 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $7.95.

This treatise on engineering thermodynamics is a sound, well written text based on the widely used heat power engineering test by Barnard, Ellenwood and Hirschfeld. The text touches on more of the current thermodynamics problem areas then earlier works on this subject while covering the normal subject matter with vigor and logic. It is definitely not the handbook type text. All of the concepts covered in the detailed treatments in the text are introduced in the first chapters, thus preparing the student for the ideas when they arise. With ample number and variety of problems included in the end of the chapters in this text, it should be suitable for use by engineering students in all branches of the engineering sciences.

However, in our opinion, the book suffers from too much brevity in several areas. A more complete founding of the idea in the early chapters is desirable. While this introduction covers many ideas, it does so without resort to either mathematical or logical introduction of the physics behind the concepts. The lack of sufficiently broad physics and mathematical background of many beginning students of thermodynamics would make the interrelations and physical reasoning behind the concepts and definitions difficult to visualize. While the subjects such as steady flow thermodynamic systems, non-flow thermodynamic systems, steady and non-steady fluid flow, turbine systems, reciprocating compressors, gas dynamics of single processes, properties of real gases, etc., are discussed, all of these items are covered as separate and distinct subjects and there appears to be no conscious effort made to show where all these different ideas are related and interdependent in this one science or discipline. The relation of the science to the kinetic theory of gases is largely ignored. There is lack of consideration of such physical interrelations and differences, such as in the related phenomena of thermal energy transfer and electrical energy transfer. While these items are not absolutely necessary to the successful practice of thermodynamic engineering, they should be introduced at an early stage in the development of the person entering research or advanced development. The book is lacking in development of the mathematical steps used to evolve many of the thermodynamic ideas in a form which can be handled in practice. The text seems to be written for persons with a strong and well used mathematical background. The lack of sufficient sample problems and diagrams adds further to the indication that this text is designed for the above average student.

While it appears to these reviewers that the book is a definite improvement over previous texts offered as a basis of study of the subject in engineering, it still does not depart far enough from the format of previous texts in the field in several aspects which the writers have found wanting in attempting to prepare students in thermodynamics for today's problems and current positions in which the engineering student finds himself in industry. For example, there are sections on theory of rotating machinery, such as compressors, pumps, and turbines, but they are rather sketchy and limited. For example, little mention is made of turbine design and performance parameters, pressure ratio optimization, efficiency at full and part load of blade design, relative to absolute velocity ratios, etc. The differences between the theories of axial flow, centrifugal and mixed flow compressors, and turbines are not brought out strongly, and the fundamental relationships which govern the design of these different types of machines are not discussed. There is too much material to cover in the current college curricula to depend on students taking detailed design courses dealing with various classes of thermodynamic machinery.

The concept of steady flow analysis is clearly presented in this text, but the writers

believe the presentation suffers from being considered separate from non-flow analysis instead of as the general case of energy balance over a system, with the non-flow system considered as a simplification or special case of the steady-flow system. It is also pleasing to note the added emphasis and clarity as well as the extent of the text which is devoted to the subject of steady state fluid flow of gases in subsonic and supersonic passages. Unfortunately, the great usefulness of the stagnation or total temperature and pressure concepts has not been brought out in the text; for example, no strong point is made of the idea that the relation between the stagnation and static values of either property can be used at any point in the flow system to determine the velocity magnitude of the fluid stream at that point. Further, the idea that the total temperature in a system is a direct measure of the total energy in that system, while total pressure is a measure of the total energy directly available for useful work is not clearly put forth. The significance of these concepts is becoming more important in interpreting thermodynamic applications. The aspect of critical values (or the state of the gas referred to conditions where it is flowing at the velocity of sound) is not made clear, although critical value relations to fluid flow are discussed. The discussion of flow in a supersonic nozzle is lacking in many respects as they are in most all thermodynamic texts. The idea of a nozzle flowing under choked and non-choked conditions and the flow phenomena existing in over- and under-expanded nozzles are unexplained. The observations of jet separation in nozzle flow in the supersonic regime are not mentioned.

While the reviewers feel the above shortcomings in the presentation, the authors have made perhaps the best compromise thus far in presenting the basic fundamentals and applications of engineering thermodynamics especially when pointed toward mechanical engineering. Much useful information has been introduced in this book and the essential theoretical criteria for design and prediction of performance of various power and fluid-flow equipment are available.

R. B. DILLAWAY and A. T. SUTOR
Rocketdyne

MICROWAVE MEASUREMENTS, by Edward L. Ginzton. 451 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $12.00.

With the advent of radar, the little explored microwave region of the radio spectrum quickly became the focal point of intense research activity aimed at gathering information which would permit the intelligent and efficient utilization of these frequencies. Measurement techniques which were well established at the lower frequencies ceased to be applicable at these extremely short wave lengths, and new methods for obtaining the required data were explored. Much of the required equipment and many of the new measurement techniques were developed during the war at the Radiation Laboratories and are described in detail in a number of papers and books published as a result of these efforts. The purpose of the present text is to consolidate much of the basic material which has appeared and present it in a form which would be suitable for a first year graduate course on the subject.

In his preface, Dr. Ginzton states that the book will provide a background for all common microwave measurements as well as for more specialized applications. A discussion of some important topics has been omitted in order to allow a more complete treatment of the material regarded as fundamental. For instance, the text does not concern itself with transmitter and receiver characteristics, antennas, propagation, measurement of physical properties of materials, or spectroscopy. It does contain a good coverage of the material indicated by the following chapter headings: 1. Generation of Laboratory Signals, 2. Detection of Microwave Power, 3. Measurement of Microwave Power, 4. Impedance Concepts at Microwave Frequencies, 5. Measurement of Impedance, 6. Representation and Measurement of Microwave Circuits, 7. Measurement of Wavelength, 8. Measurement of Frequency, 9. Resonant Cavity Characteristics, and 10. Measurement of Attenuation. Appendices at the end contain charts of field patterns corresponding to various modes in waveguides, tables of cut-off wavelengths in waveguides, and tabulations of formulas and constants used in many of the derivations.

The text covers much of the same material as Volume 11 of the Radiation Laboratory Series, "Technique of Microwave Measurements," but with considerably less detail and in a style better adapted to the needs of the student. In addition, Professor Ginzton's book touches on some developments which have come into being since the publication of the Radiation Laboratory Series. Travelling wave tubes, pencil triodes, and molecular oscillators or MASERS are examples. *Microwave Measurements* is a well written and easily read book, and it is felt that the student should be able to follow the material presented with ease. Sufficient background theory is developed to present the reader with a fundamental understanding of the principles involved. Adequate references are included to draw attention to papers having more detailed discussions of important topics. While the book is ideally suited to its purpose, namely, a graduate course in microwave measurements, it is felt that it will also establish itself as a useful reference for workers in the field having an interest in measurement problems.

D. L. BIRX
The Franklin Institute Laboratories

THERMAL STRESSES WITH APPLICATIONS TO AIRPLANES, MISSILES, TURBINES, AND NUCLEAR REACTORS, by B. E. Gatewood. 232 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $7.50.

To use the author's own words, this book "touches on all phases of the structural design problem—the temperature distribution, the elastic and inelastic applied and thermal stresses, the allowable stresses for various materials and loading conditions, the buckling, deflection, stiffness, fatigue, shock and flutter effects of elevated temperatures." The words that should be emphasized in this statement are "touches on."

The first four chapters, almost half of the book, are devoted mainly to aerodynamic heating and thermal stresses for one-dimensional temperature distribution. In Chapters 5 and 9, some simple two-dimensional thermal stress problems are discussed. All other items are covered in the remainder of the book.

The book is apparently intended mainly for the practical aeronautical engineer. A large portion of the book deals with the subject of aerodynamic heating; and the discussion of the properties and behavior of materials at elevated temperatures relates principally to aircraft structures. The very brief discussion of thermal stresses in turbine blades, turbine disk and reactor vessel hardly justifies the author's claim in the title of this book.

Lack of adequate information concerning the thermal effects on the behavior of structural materials at elevated temperatures at the present time may have limited the scope of presentation on some topics in this book, for example, thermal fatigue. On the other hand, some gross omissions of the basic theory of thermo-elasticity and the use of some oversimplified assumptions in the evaluation of thermal stresses detract appreciably from the usefulness of the book. The thermo-elastic equations presented in Chapter 1 are scarcely referred to in later chapters. Some amplification on the discussion of two-dimensional thermal stress problems and thermal stresses in plates and shells would help to acquaint the readers with the nature of the stress problems of structural members arising from temperature variation. In discussing the inelastic thermal stresses it would seem to be appropriate also to include some fundamentals of the theory of visco-plasticity which begins to find its applications in engineering design. Otherwise, considering the level of mathematical treatment in the book as a whole, the inclusion of a brief discussion of variational methods and methods by using complex variables in Chapter 9 seems somewhat out of place.

Although the book is limited in scope on some general aspects of thermal stresses, the author should nevertheless be given credit for the difficult task of writing the first English textbook on thermal stresses.

T. C. YEN
The Franklin Institute Laboratories

THE SCIENCE OF ENGINEERING MATERIALS, by J. E. Goldman. 528 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Limited; 1957. Price, $12.00.

This book is based on a symposium held at Carnegie Institute of Technology in 1954 by

leading solid state scientists. The lectures from the symposium have been rewritten by the contributors to form chapters and have been edited into a single text by Dr. Goldman. The editor points out that the lectures resulted from a need to impart a fundamental approach to the understanding of engineering devices and materials. As a metallurgical engineer working intimately in the field of solid state physics, this reviewer can agree that a greater emphasis on the basic approach is urgently needed. However, most books, papers, and lectures by the physicist directed toward the engineer, purportedly to fulfill this need, fall far short of their goal. They generally only serve to convince the engineer that there can be no hope for him unless he goes back to school and studies to be a physicist.

The first chapter by the erudite Prof. Brooks should go far toward dispelling the fears of the engineer concerning the difficulties of such a book. It is an extremely straightforward general survey on the applications of solid-state physics in engineering. It gives the engineer the courage to read more of the book. Surprisingly enough, the subsequent chapters prove only slightly more complex. The authors and editor have done a remarkably good job in presenting difficult concepts in an uncomplicated way.

Subjects such as electron theory, dislocations in solids, magnetism, semiconductors and surface phenomena are treated in a relatively simple fashion. Clearly, some mathematical descriptions are essential; however, these are kept to a minimum and require little more than a good knowledge of the calculus. This does not mean that the book is simplified to the extent that it is of little technical value. Reducing each subject to its bare essentials and presenting it without all of the details of mathematical derivations should make it understandable and palatable to the engineer. When he has finished studying this text, he should be able to have some feeling for such concepts as the Fermi Level, the p-n junction, etc.

Although the book is devoted primarily to basic principles and crystalline substances, there is a chapter each on cement, polymers, and glass. The treatment in these chapters is somewhat different in that there is less of a solid state science approach to the problem involved. For instance, Dr. Brunauer points out that cement is too complicated a system to attack with the theoretical tools of solid state science. His treatment of the subject is primarily one of physical chemistry. Dr. Davies aptly remarks on his contribution that a discussion of glass can be made a part of the mainstream of the volume only with some forcing.

Dr. Goldman had done a creditable job in editing the volume without losing sight of the motivation for its publication. It is a major step toward breaching the gap of mutual misunderstanding between the physicist and the materials engineer.

R. L. SMITH
The Franklin Institute Laboratories

ELASTIC WAVES IN LAYERED MEDIA, by W. M. Ewing, W. S. Jardetzky and F. Press. 380 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $10.00.

Nature is in truth, we know, furiously complicated. If we forbear from looking too close, however, we usually find that rather simpler mathematical models will serve to illuminate most natural phenomena. In this excellent work, which is likely to remain a basic reference for a long time to come, the authors have assembled a great deal of information about a class of models which has proved most fruitful in the study of geophysical and acoustic problems.

Of the seven chapters, four are devoted to developing the basic theory of wave propagation in homogeneous strata. The solutions available are presented and thoroughly discussed for: the infinite space, the half-space, two contiguous half-spaces, and a half-space surmounted by one or more layers. The organization is systematic and logical. Treatment is primarily mathematical, but the authors have worked in substantial references to experimental work wherever possible, a feature which adds greatly to the usefulness of the book.

The three final chapters concern: modifying effects of gravity, curvature, and viscosity; applications to plates and cylinders; and the more difficult problem, on which much less work has been done, of wave propagation in heterogeneous media. Appendices discuss

the method of steepest descent and Rayleigh's principle, but are so brief as to be of doubtful value. The very useful and unusually comprehensive bibliography contains 650 references.

WILLIAM C. YAGER
The Franklin Institute Laboratories

THE ECONOMICS OF NUCLEAR POWER, edited by J. Gueron, J. A. Lane, I. R. Maxwell and J. R. Menke. 513 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $17.00.

This book, the eighth volume in a series of books on nuclear energy published by McGraw-Hill, concerns itself with as many of the aspects of the economics of nuclear energy as are currently available. It is conveniently divided into five parts: Needs and Resources, Nuclear Power Economics, Nuclear Fuel Cycles, Reactor Programmes and Reactor Economic Data, and Administration and Law. Each part is a series of separate papers written by qualified men and assembled in a unified form by the editors.

The first part, Needs and Resources, is, as the title suggests, a discussion of the power needs and resources of as many of the world countries as are now known. There are papers on such subjects as world energy requirements in 1975 and 2000, resources of conventional fuels, economic growth and energy consumption, the role of atomic power in India, and the Brazilian Plan of electrification. In part two, Nuclear Power Economics, there are such papers as the Geneva and Post-Geneva Nuclear Power economic data, the atomic power market in the United States and overseas, and capital investment required for nuclear energy. In part three, Nuclear Fuel Cycles, such subjects are covered as an introduction to papers on fuel cycles, fuel cycles and types of reactors and the reactivity changes and reactivity lifetimes of fixed-fuel elements in thermal reactors. In part four, Reactor Programmes and Reactor Economic Data, there are papers on the graphite-moderated, gas-cooled pile and its place in power production; the objectives and summary of USAEC civilian power reactor program; and reactor economic data. In part five, Administration and Law, we find such papers as the administration problems in the industrial utilization of atomic energy, safety criteria in atomic energy, the general problems of protection against radiations from the public health point of view, and a brief survey of the United States Atomic Energy Act of 1954.

The editors and McGraw-Hill have performed a very useful service in gathering and assembling in one volume significant papers on the current status of the economics of nuclear power. Of course, because nuclear power is still in its infancy, there is much yet to come, but it marks a worthwhile beginning in the long accumulation of such data.

E. W. HAMMER, JR.
The Budd Company

BRITTLE BEHAVIOR OF ENGINEERING STRUCTURES, by Earl R. Parker. 323 pages, illustrations, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $6.00.

The interest in the *Brittle Behavior of Engineering Structures* was stimulated during World War II by the numerous failures in welded steel merchant ships. This type of failure has also occurred in bridges, penstocks, storage tanks and pipelines. At the request of the Ship Structures Committee, The National Academy of Sciences—National Research Council originally planned to prepare a monograph on improvements of hull structures of ships. The final outcome was the organization of a project advisory committee composed of a group of experts on various aspects of the problem. The committee obtained the services of Professor Earl R. Parker as the author of this book.

Since the purpose of the book is to summarize the available information on the brittle behavior of steel in engineering structures, each chapter of the book is devoted to a technical aspect of the problem. To mention a few of the subjects of interest, they are the concept and theories of fractures, test methods and results, special steels, composition of steels, welding, residual stresses, design and workmanship, service failures, and the final chapter is a summary on the subject. Each of the chapters is an interesting and comprehensive treatment of its subject. As a conclusion to most of the chapters is a summary of its subject which is very helpful.

Anyone reading this text will come to realize

that the failure of engineering structures has been in existence ever since iron and steel have been produced as materials of construction. Also, that structures must be properly analyzed and designed. It can be truthfully stated that this is usually done. Above all the structure must be properly constructed. This is borne out by the findings that defective welding has been largely responsible for most of the recent structural failures in service.

This text will not supply the answers to all the problems that confront the engineer in designing welded structures. There is no doubt that it will aid him in taking the proper precautions and thus reduce the number of catastrophic failures in the future.

A. O. BERGHOLM
The Franklin Institute Laboratories

ACOUSTICS, by Joseph L. Hunter. 407 pages, diagrams, 6½ × 9 in. Englewood Cliffs (N. J.), Prentice-Hall, Inc., 1957. Price, $8.50.

Professor Hunter's new book could be divided for the purpose of review into three principal portions. The first of these groups covers the classical development of oscillating systems such as masses and springs, vibrating strings, and finally waves in air. Starting with these, he requires of the reader a general knowledge of physics and calculus, including some partial differential equations. Because of the widespread use in acoustics of electroacoustic analogies and the mathematical approach of the electrical engineer, familiarity with electric circuit theory is a distinct asset in following Professor Hunter's presentation.

Proceeding secondly to the practical applications, loudspeakers, microphones, and recording are treated at considerable length. In the analysis of these devices equivalent circuits are given, and a rather conventional mathematical treatment is presented. Architectural acoustics and acoustic measurements related to the design of corrective devices are treated briefly. That is, the material presented is brief in comparison to that available in well-known references by Olson, Beranek, and Bolt.

Related to the general field and applications of acoustic engineering are the subjects of speech, hearing, noise, and intelligibility. Comprising a third type of material, distinct from classical theory or applications, this portion of the book is mainly a discussion of data. Collected here are some of the results of the well-known subjective measurements associated with the name, Fletcher, and others.

Thus Professor Hunter's book is a convenient collection of classical theory, applications and pertinent data in the field of acoustics. Perhaps we should say "sonics," for, as discussed below, he touches upon phenomena which have frequencies above the upper limit of human audition. It is not as complete in any particular as the references cited, but it does bring together a number of related basic subjects in acoustics.

The author has added to the scope of his book by recognizing that the field of ultrasonics is gaining genuine commercial importance. One chapter therefore presents in analytical terms a number of interesting aspects of the propagation of sound at frequencies above the audio. This is the more general theory of sound where certain tacit assumptions about the medium being dissipationless are not applicable. Here the author formulates hypotheses and constructs models to explain results which simpler forms have failed to explain. The instrumentation of ultrasonics is not treated. For this information the reader would profit more by referring to Alan E. Crawford's book, "Ultrasonic Engineering."

If Professor Hunter's book is used as the basis for a course on acoustics, it is suggested that some supplementary laboratory instruction accompany the work. This would materially help the student to visualize the subject matter which is intensely interesting in the laboratory as well as the classroom.

C. W. HARGENS
The Franklin Institute Laboratories

DIGITAL COMPUTER PROGRAMMING, by D. D. McCracken. 253 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1957. Price, $7.75.

There have been books published on the subject of digital computers but most of them

have been directed toward some specific area of application. This book is actually the first of its kind, being devoted to the fundamentals common to all digital computers from the user's point of view. The person who wants to use a computer to solve a problem does not initially care about machine logic, circuitry, the advantages and disadvantages of drums, acoustic delay lines, magnetic cores, flip-flops, knick-knacks and dodads. He would rather accept the fact that there are such things and then concentrate on how to use them to solve his problem. *Digital Computer Programming* is written primarily for this person.

To accomplish his purpose the author creates on paper a computer called TYDAC, which stands for TYpical Digital Automatic Computer. TYDAC has features which are found in various contemporary computers. Such a computer probably would never be manufactured exactly as described but it serves very well as a learning device. With "programming the TYDAC" as the ultimate objective, the book proceeds in textbook fashion to discuss the general concepts of different number systems, flow charting, fixed and floating point methods, subroutines and automatic coding techniques. Whenever possible comparisons are made between TYDAC and existing machines. Hence, there is something in this book for the person who already knows programming on a particular computer but is lacking, perhaps, in the knowledge of other computers.

Digital Computer Programming could be used quite successfully as a text for a first course in programming, provided the class was sufficiently trained in mathematics to appreciate some of the sample problems (anyone who knows what a Taylor series is may be admitted to the class). Many exercises are included at the end of each chapter.

The reviewer believes the author, D. D. McCracken, has done a service in writing this book. He has compiled between two covers information which heretofore was scattered in many different articles, manuals and papers—furthermore, he has done it cleverly with his TYDAC.

LAURENCE C. MCGINN
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APPLIED METALLURGY FOR ENGINEERS, by Malcolm S. Burton. 407 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $7.50.

This book has been written as a text for a survey course in metallurgy. For the level of information required for non-majors in metallurgy, the author has succeeded in developing the present day metal processes out of their associated metallurgical principles. The difficulty of presenting descriptive material along with fundamentals has been resolved. The student discovers the "whys" of a process and also is given sufficient details on how the process is done.

The first few chapters of the book are devoted to metallurgical fundamentals and to the tools and methods used in metallurgical investigations. They form the necessary ground work for the combination of more advanced fundamentals and associated descriptive material which follows.

The remaining chapters cover the production of metals; the principles and techniques of heat treating; the foundry process; the theory and methods of metal working; and the bonding of metals.

All the techniques associated with any metal processing appear to have been mentioned, though in many cases very briefly. The book is very useful as a source of available processes to the design engineer. In this respect it could be improved by comparing the metallurgical and economical factors of various processes more rigorously.

In general the photographs of equipment, the photomicrographs of metal sections, the graphs, and the drawings were excellently depicted and clearly understood.

The book, as it was meant to be, is an excellent text describing metallurgical technology.

MARVIN HERMAN
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BOOK NOTES

PRINCIPLES OF PHYSICAL SCIENCE, by Francis T. Bonner and Melba Phillips. 736 pages, illustrations, 6 × 9 in. Reading (Mass.), Addison-Wesley Publishing Co., Inc., 1957. Price, $7.50.

As a new text for liberal arts students desiring a physical science course, this book should be of interest to general readers as well. The authors have assumed that this course would be the only one in college science, and so they have built their text around the central theme of the growth of man's ideas concerning the physical world. There are thirty chapters devoted to various fields of science, including such topics as The Solar System, The Law of Universal Gravitation, Matter and Its Classification, Heat and the Conservation of Energy, Wave Motion, Rocks and Their Formation, etc. The sequence of chapters follows the historical development of the physical sciences, and so the whole picture is presented chronologically. The text is suitable for college freshmen and requires only a knowledge of elementary algebra. The text has been used successfully at Brooklyn College.

CENTRIFUGAL AND AXIAL FLOW PUMPS, by A. J. Stepanoff. Second edition, 462 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $12.00.

The second edition of this text has been expanded to include a chapter on "Water-Hammer Problems in Centrifugal Pump Systems," new material on centrifugal-jet systems, thermal cavitation criterion, and complete characteristics of axial and mixed flow pumps. The original text has been revised to add design refinements and a new viscosity chart. Throughout, the author has included the developments in theory, design and application which have come about since the first edition was published in 1948.

SYSTEMATIC ORGANIC CHEMISTRY, THEORY AND APPLICATIONS, by Hugh C. Muldoon and Martin I. Blake. 828 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $7.75.

Emphasizing biological applications, this text is intended for beginners in general organic chemistry. The book follows the general order of presentation used in Muldoon's "Organic Chemistry," but differs from it in purpose and content. The present text includes discussions of new theories and new interpretations, with much of the factual material set forth in tables to give more space for discussion of the newer theories. Although emphasis is on principles and applications, current industrial methods for manufacturing important synthetics are discussed.

PHYSICS FOR SCIENCE AND ENGINEERING, by Robert L. Weber, Marsh W. White and Kenneth V. Manning. 618 pages, illustrations, 7 × 10 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $8.00.

The present book has evolved from its predecessor "College Physics." The objective is to introduce the basic concepts and principles of general physics for students of physics and engineering at the university level. Further, the book is designed to develop the reasoning power of the student instead of his memory. To achieve this goal, the authors have stressed the understanding of the fundamental ideas, principles and methodology of physics rather than mere fact and formula.

TRANSISTOR CIRCUITS, by Rufus P. Turner. 160 pages, diagrams, 5½ × 8½ in. New York, Gernsback Library, Inc., 1957. Price, $2.75 (paper).

The author, a licensed professional engineer, has prepared this practical work book for electronic technicians, engineers and experimenters. He lists over 150 practical transistor circuits, all of which he has tested himself. For those engaged in work using transistors, this handbook will save many hours of experimenting. Eleven chapters cover such devices as audio amplifiers, RF, IF and d-c. amplifiers, oscillators, power supplies, radio receivers, test instruments, etc.

THERMODYNAMICS, by Virgil Moring Faires. Third edition, 543 pages, illustrations, 6 × 9 in. New York, The Macmillan Co., 1957. Price, $7.50.

The third edition of this standard text has been issued because of the growth in the con-

cept of entropy. The whole work has been rewritten and reorganized. One change from the two previous editions is the introduction of most of the basic theory at the beginning, rather than scattered throughout the text. A separate book on problems (by Faires, Brewer and Simmang) provides more than ample material without cluttering up the main text. As in previous editions, the text is designed for a full year's course, although it can be adapted to a one-semester one.

GLASS REINFORCED PLASTICS, edited by Phillip Morgan. Second edition, 276 pages, illustrations, 6 × 9½ in. New York, Philosophical Library; London, Iliffe & Sons, Ltd.; 1957. Price, $15.00.

New material in this edition includes chapters on epoxide resins, the resin injection molding process and on chemical plant applications. The bulk of the text remains essentially unchanged, and it covers raw materials, fabrication techniques and special applications (for example, automobile bodywork, boat hulls, piping, swimming pools, furniture, etc.).

AN INTRODUCTION TO REACTOR PHYSICS, by D. J. Littler and J. F. Raffle. Second edition, 208 pages, diagrams, 5½ × 8½ in. New York, London and Paris, Pergamon Press Inc., 1957. Price not given. U. S. A. edition available from McGraw-Hill Book Co., Inc.

This second edition has been prepared primarily to correct errors in the first edition and to amplify certain sections. New material has been added to include a discussion of the Breit-Wigner formula and the Doppler broadening of resonances. In addition, new data have been included as a result of declassification at the United Nations Geneva Conference in 1955. Nearly all chapters have undergone some revision, and Chapter 11 on reactor kinetics has been rewritten to conform with the treatment used by other authors.

ELEMENTARY SOIL AND WATER ENGINEERING, by Glenn O. Schwab, Richard K. Frevert, Kenneth K. Barnes and Talcott W. Edminster. 296 pages, illustrations, 5½ × 8½ in. New York, John Wiley & Sons, Inc., 1957. Price, $6.25.

A brief survey of several topics useful to the modern agriculturist, designed as an elementary college text. Eighteen chapters discuss topographic and land surveying, irrigation and drainage, and erosion and its control. The treatment is generally sketchy, sometimes to the point where usefulness and intelligibility are seriously impaired. It is very doubtful, for instance, that the section on plane table surveying would provide an adequate basis for understanding even with an instructor present to explain. The more strictly agricultural subjects fare better than surveying; nevertheless this text probably cannot be successfully used outside a classroom, though the authors claim the contrary. A number of excellent and detailed laboratory problems are included in an appendix.

PUBLICATIONS RECEIVED

The Editors wish to call attention to these new books, received in the JOURNAL office for review. Lack of space prevents publication of more than this listing.

ELEMENTS OF HEAT TRANSFER, by Max Jakob and George A. Hawkins. Third edition, 317 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $6.75.

BASIC MATHEMATICS FOR RADIO AND ELECTRONICS, by F. M. Colebrook and J. W. Head. 359 pages, diagrams, 4¾ × 7¼ in. New York, Philosophical Library, 1957. Price, $6.00.

CONSTRUCTING AN ASTRONOMICAL TELESCOPE, by G. Matthewson. Second edition 100 pages, illustrations, 5 × 7½ in. New York, Philosophical Library, 1957. Price, $3.00.

A TEXTBOOK OF DAIRY CHEMISTRY, by Edgar R. Ling. Third edition revised. Vol. 1, Theoretical; Vol. 2, Practical. 227 pages and 140 pages, illustrations, 5½ × 8½ in. New York, Philosophical Library, 1957. Price, $12.00 the set.

ANTARCTIC HAZARD, by W. Ross Cockrill. 230 pages, illustrations, 5 × 7¾ in. New York, Philosophical Library, 1957. Price, $4.75.

Irradiation Changes in Metal Crystals Studied.—General Electric scientists at the Atomic Energy Commission's Hanford plant have discovered new ways to study the changes that occur in tiny structures like metal crystals that have been exposed to the storms of radiation inside an atomic reactor. Bernard Mastel told members of the Electron Microscope Society meeting at Massachusetts Institute of Technology of work being done at the Hanford, Washington, plutonium plant to learn more about these changes.

Interpretation of changes arising from irradiation is made easier if the identical area of a specimen is examined before and after treatment. But once a piece of uranium, for instance, has been irradiated in a reactor it becomes too radioactively "hot" to be handled readily.

Hanford scientists have found a way to avoid all but a minimum of handling of uranium specimens. They make plastic replicas of the samples before and after irradiation.

Uranium specimens used are half-inch discs which are polished, etched, scribed and duplicated in cellulose acetate before being canned for irradiation inside an atomic reactor.

After irradiation for a known period of time the specimens are removed from their capsules and again duplicated by remote control means with cellulose acetate. The replicas are then compared to determine the structural changes which took place during irradiation.

Cellulose acetate has the advantages of being easily applied and stripped by remote means, it doesn't become radioactive, it gives a permanent record of the specimen and serves as the basis for preparing additional replicas for optical and electron microscopy.

Comparison of uranium samples before and after irradiation can be made at various levels of magnification. These studies provide a better understanding of the effects of irradiation on the structures of materials.

With the aid of optical or electron microscopes Hanford scientists can study the specimen at magnifications ranging from zero to 50,000 times natural size. They can study the same grain at any desired level of magnification before and after irradiation and detect even the smallest change brought about by exposure in the reactor.

Mica Mat Insulation.—Mica mat insulation is a cardinal factor in a new manufacturing process recently developed by the Ford Motor Company. The new process is expected to save the company thousands of dollars annually.

Mica mat, produced by the General Electric Company's Insulating Materials Operation, is being used by Ford to insulate copper segments in commutators used in automobile generators and starters.

In the new process at Ford, the commutator can now be assembled automatically—as contrasted with an operation that formerly involved a high degree of hand work and a copper-wasting segment configuration.

The use of smooth-surface mica mat made possible the development by Ford of a commutator design and automatic process, resulting in a sizeable savings in copper. Physical re-

quirements dictate the use of a mica insulation. Revolving at 12,000 rpm. and higher, the commutators develop operating temperatures of about 160° C. A mica material is considered the only satisfactory insulation between the commutator segments because of high resistance to heat and to the pressures generated by the rapid rotation.

Mica mat is capable of being heated red hot without burning. The thin segments are supplied to Ford by General Electric, which pioneered mica mat development in the United States.

Composed of tiny bits of reconstituted mica bound together in a continuous sheet, mica mat eliminates temperature limitations imposed by cellulose materials as well as the surface irregularity of conventional mica forms. In addition, the unique process used in the manufacture of mica mat makes possible extremely close control of thickness tolerances—to plus or minus 0.0005 in., which is approximately one sixth the diameter of a human hair.

Mica mat is manufactured by the General Electric Company's Insulating Materials Operation in rigid sheets, composites, wrappers, and tapes—the latter two in thicknesses down to one mil.

New Integrated Chemical Proportioner.—A new chemical proportioner has been developed by The Johnson-March Corp., Philadelphia, to proportion its surface active wetting compound with water automatically and pump the mixed solution at variable rates of flow. The new unit, known as the Type S liquid proportioner, is used with the latest of the company's Chem-Jet liquid dust control systems. Pump, motor and proportioner are now incorporated inside one housing to save space and protect equipment from the weather and physical damage.

Capacity range has been extended, with one model delivering the mixed wetting solution at from 0 to 50 gpm., and another at a rate of 40 to 100 gpm. Larger sizes are specially made for capacities up to 500 gpm. Standard inlet pipe sizes are 1, 1¼ and 1½ in.

A dual tank system is employed offering nearly three times the usable storage capacity formerly available for the mixed Compound MR-water solution. A heavy gauge steel housing is provided for the proportioning equipment, pump and motor, and an 18 gauge stainless steel tank stores up to 130 gallons of the mixed solution. The stainless tank is more resistant to corrosion and more durable than the rubber-lined tank formerly used.

The unit is equipped with a newly designed micro-bellows type pump which gives precise control over the amount of compound proportioned into the water line. This new pump is used in place of an eductor and rotometer, which permits more accurate, variable-flow proportioning than previously possible.

In operation, the proportioner measures and pumps the surface active concentrate into the water, pipes the mixed solution into the ready storage tank, and then conveys the final liquid at variable rates of flow to the points of application in the dust control system.

The basic proportioner, supplied as a complete assembly, is 52 in. high, 40½ in. wide and 40½ in. deep. It weighs 900 lb. Installation requires only water supply, pump discharge and electrical connections.

All necessary accessories are supplied including parts for the water inlet assembly, solution discharge assembly and Compound MR inlet assembly.

High-Speed Switching Transistor.—A new type of transistor that "approaches the ideal electronic switch" for high-speed switching functions in electronic computers and automatic control systems has been developed experimentally by scientists of the Radio Corporation of America, it was announced recently by Dr. Irving Wolff, Vice President, Research.

The new device, called the "Thyristor," was described by Dr. Wolff as "a marked advance" over both gas tubes and existing transistor switching devices because of its combination of simplicity, speed and "extremely low" power requirements.

"The 'Thyristor' has a number of characteristics which come close to the ideal for high-speed switching functions," said Dr. Wolff. "Among these are its ability to switch substantial currents from one circuit to another in periods as short as one fifty millionth of a second, and its ability to switch from 'Off' to 'On' and vice versa simply by the application of low energy pulses to the base circuit in one polarity or the other. This bi-stable performance characteristic will now permit us to do with one transistor a job that has previously required two."

The "Thyristor" was developed by an RCA Laboratories research team including C. W. Mueller, J. Hilibrand, and L. E. Barton, members of the technical staff at RCA's David Sarnoff Research Center here.

Discussing the new device, Doctors Mueller and Hilibrand pointed out that the "Thyristor" may be operated either as a bi-stable switching element or as a more conventional high-frequency transistor, either in switching or in amplifying circuits.

They pointed out that while the new device has many of the properties of existing types of gas switching tubes, it is "markedly superior" in many respects as a high-speed switching device. They stated, for example, that the commercial gas switching tube cannot be switched "Off" from the control element in the same way that it is switched "On," whereas the "Thyristor" is switched either way simply by changing the polarity of low energy pulses applied at the base.

Among the other principal advantages of the new device, according to the two scientists, are:

1. In operation it has an extremely low sustaining voltage, "of the order of a half volt at 100 milliamperes," permitting good "On/Off" stability.
2. It conducts very little current in the "Off" position, "amounting to about 2 microamperes," which provides for a high-impedance "Off" position.
3. It permits the use of simple circuitry for switching.
4. Fabrication of the "Thyristor" is "simple and can be carried out with ordinary diffusion and alloy techniques."

Doctors Mueller and Hilibrand described the "Thyristor" as a modified alloy-junction transistor. A novel feature, they said, is a new form of collector contact which makes possible the high-speed switching action.

The device is still under development, they pointed out, and is not yet commercially available.

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